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POTENTIAL OF CEREAL BY-PRODUCTS FROM ETHANOL PRODUCTION AS FEED INGREDIENTS FOR SWINE PRODUCTION

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Final Report

Potential of Cereal By-Products from Ethanol Production as Feed Ingredients for Swine Production

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ADF Program

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Summary

With the tremendous growth of the ethanol industry, more and more by-products - namely, distiller's grains and thin stillage (DDGS) are available for livestock rations. The nutritional value of dried wheat distiller's grain for grower-finisher pigs was prior to start of the project unknown, especially the value of wheat DDGS produced in western Canada.

The main objectives for a series of experiment were to: a) characterize the nutritional value of wheat-based DDGS, b) to determine the impact on nutrient excretion, c) optimize feed strategies, and 4) to detect impact on carcass quality. Therefore, to study this feedstuff, the project was initiated with a digestibility experiment with cannulated grower-finisher pigs fed one wheat control diet and 3 dried distiller's grain diets (corn, corn and wheat, and wheat distiller's grain). Ingredient, feed, faeces, and digesta samples were collected and were analyzed to determine DE, digestible amino acid, and digestible phosphorus content for the three DDGS samples. This first project indicated in total that wheat DDGS can be used as a feedstuff for swine, but has a lower nutritional value than the parent wheat. However, feeding of wheat DDGS, in particular poor quality wheat DDGS might reduce voluntary feed intake. Feeding of wheat DDGS will increase N excretion, and may reduce P excretion, due to high P digestibility due to degradation of phytate. As such feed wheat DDGS to nursery and grower-finisher pigs may have to be limited to 10 to 20%, for poor quality wheat DDGS, whereas wheat DDGS might be fed up to 30% in finisher pigs, if a good or excellent quality. If proper diet formulation is used (NE and SID AA content), impact on carcass quality is limited but dressing percentage will be reduced by 1 to 2% due to a higher weight of the gastro-intestinal tract due to the additional fibre in the diet.. In a series of follow-up experiments, supplemental enzymes were studied to alleviate the reduced nutrient digestibility and voluntary feed intake; however, supplemental enzymes proved less effective than expected. In collaborative project, effects of feed processing especially extrusion technology have been studied. In conclusion, wheat-based DDGS can be added to feedstuffs databases for feed formulation for swine.

Introduction

The current project is a continuation of ADF Project # 20020139. Since the final report for that project was prepared, a literature review was prepared, and five studies and 2 book chapters have been entirely completed. One set of studies has been published as a scientific journal article, and one set of studies has been submitted for peer-review. Other studies were completed as part of ongoing collaborations, but are not part of this report. Each study and chapter is defined in detail as appendixes in this report.

Methods

The methods used on the present set of studies entailed: a) digestibility studies to characterize nutrient digestibility and digestible nutrient values; b) growth performance studies to look at growth performance and make prediction on carcass quality; and c) studies to evaluate technologies to improve the nutrient digestibility of wheat-based DDGS. As part of this reported

work, liquid feeding was not conducted, because commercially-available materials is only available in dried from. Instead, more emphasis was placed on improving the feed management of pigs fed diets containing wheat DDGS, because that is the main limitation moving the industry forward. However, quality of freeze-dried DDGS has been analyzed as part of a collaborative project, indicating that numerous bioactive compounds exist in distiller's grain and in solubles (data not shown).

Results

The results of the studies indicate that wheat DDGS has a lower nutritional value than corn DDGS and wheat. The nutritional value of wheat DDGS can be improved using technologies processes such as particle size reduction and phytase supplementation, but not with xylanase supplementation. DDGS can be fed to pigs in diets formulated to equal NE and SID AA content; however feed of poor quality DDGS will then result in reduced growth performance mainly due to reduced feed intake, whereas growth performance does not change with good quality DDGS. Feeding wheat DDGS does not change carcass quality but will reduce dressing percentage.

|Conclusions and Recommendations

Wheat DDGS is feedstuffs suitable to feed to swine. Even though its nutritional profile might link it foremost to ruminant nutrition, using a firm percentage of good quality wheat DDGS in swine diets results in equal growth performance, similar carcass quality, except dressing percentage, and increased nutrient excretion.

The project will continue as a part of an ABIP-project, which is a collaborative effort between scientists in Saskatchewan and Alberta.

|Literature Cited

Literature is cited with each of the specific contributions in the appendices. These specific contributions generated from this project are listed under 'Project Developed Materials' below.

Appendices

The current project is a continuation of ADF Project # 20020139. Since the final report for that project was prepared, a literature review was prepared, the fives studies were completed in its entity. For each of these, a final report is included as an Appendix. To keep the length of the document in check, references were not included in some of the reports that have not been finished yet for peer-review. The rest is complete.

Personnel

Gemunu Widyaratne has been working on the project as the primary graduate student. Thomas Nortey and Jorge Yanez have provided assistance as Ph.D. students for the projects. Miladel Casano has provided laboratory technician assistance. Laura Kiehlbauch was working on the project as an animal research technician. Regular animal care was also provided by Prairie Swine Centre's core technical staff.

Equipment

Equipment was not purchased.

Project Developed Materials

Apart from reports to the sponsors of the project, the following materials were prepared:

Peer-reviewed articles

Widyaratne, G. P., and R. T. Zijlstra. 2007. Nutritional value of wheat and corn distiller's dried grain with solubles: digestibility and digestible contents of energy, amino acids and phosphorus, nutrient excretion and growth performance of grower-finisher pigs. Can. J. Anim. Sci. 87:103–114.

Widyaratne, G.P. and Zijlstra, R.T. 2008. Erratum. Nutritional value of wheat and corn distiller's dried grain with solubles: digestibility and digestible contents of energy, amino acids and phosphorus, nutrient excretion and growth performance of grower-finisher pigs. Can. J. Anim. Sci. 88: 515-516.

Widyaratne, G. P., J. F. Patience, and R. T. Zijlstra. 2008. Effect of xylanase supplementation of wheat distiller's dried grains with solubles on energy, amino acid and phosphorus digestibility and growth performance of grower-finisher pigs. Can. J. Anim. Sci. (Submitted, CJAS08103).

Book chapters

Patience, J. F., P. Leterme, A. D. Beaulieu, and R. T. Zijlstra. 2007. Utilization in swine diets of distillers dried grains with solubles derived from corn or wheat used in ethanol production. Pages 89–102 in Biofuels: implications for the feed industry, J. Doppenberg and P. van der Aar, eds. Wageningen Academic Press, Wageningen, The Netherlands.

Zijlstra, R. T., and E. Beltranena. 2008. Variability of quality in biofuel co-products. Pages 311-324 in Recent Advances in Animal Nutrition – 2008. P. Garnsworthy and J. Wiseman, eds. Nottingham Academic Press, Nottingham, UK. (In Press).

Scientific abstracts

Widyaratne, G. P., R. T. Zijlstra. 2005. The effect of enzyme supplementation on energy and crude protein digestibility of wheat distiller's dried grains with solubles in grower-finisher pigs. J. Anim. Sci. 83 (Suppl. 1): 390. [Abstract]

Widyaratne, G. P., J. F. Patience, R. T. Zijlstra. 2004. Nutritional value of wheat and corn distiller's dried grain with solubles (DDGS): digestible energy (DE), amino acid and

phosphorus content and growth performance of grower-finisher pigs. Can. J. Anim. Sci. 84: 792. [Abstract]

Yanez, J. L., E. Beltranena, R. T. Zijlstra. 2009. Effects of phytase and xylanase supplementation and particle size on nutrient digestibility of distillers dried grains with solubles co-fermented from wheat and corn in cannulated grower pigs. J. Anim. Sci.. (Submitted)

Conference proceedings

Zijlstra, R. T., and E. Beltranena. 2008. Using bio-fuel by-products in feed. Feed mill workshop, Feb 20, Nova Scotia Agricultural College, Truro, Nova Scotia.

Beltranena, E., and R. T. Zijlstra. 2008. Containing feed cost using biofuel coproducts. Advances in Pig Production. Proc. Banff Pork Seminar. pp. 263-273.

Zijlstra, R. T., G. Widyaratne, and E. Beltranena. 2007. Characterization of wheat DDGS and feeding to swine. Proc. 28th Western Nutr. Conf., Saskatoon, SK. pp. 207-213.

Research reports

Widyaratne, G. P., R. T. Zijlstra. 2005. Nutritional value of corn and wheat distiller's dried grain with solubles: digestibility and digestible contents of nutrients and growth performance of grower-finisher pigs. 2004 Annual Research Report, Prairie Swine Centre Inc., Saskatoon, SK. p. 32-33.

Thesis

Widyaratne, G. 2005. The nutritional value of wheat distiller's grain for pigs. M.Sc. Thesis, University of Saskatchewan, Saskatoon, SK. Thesis accepted.

Project Photos

Photos were not taken.

Acknowledgements

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Appendix 1 Literature Review

1.1 Introduction

Widespread interest exists in many regions of the world, particularly in the United States, in producing ethanol from cereal grains for use as a fuel additive. The ethanol industry is therefore expanding rapidly. The trend of increased ethanol production is moving into Canada as well [Agriculture and Agri-Food Canada (AAFC) 2004]. Escalating fuel prices, comparatively low grain prices, opportunities for rural development, and environmental concerns can be considered as the major reasons for this interest. Furthermore, cereal grains are renewable energy sources while fuel produced from crude oil is not (Lipinsky 1981). Therefore, the abundant grain supplies in North America and diminishing fuel resources can be other reasons behind this interest. Finally, the quantity of ethanol produced by the fermentation of cereal grains continues to increase due to the high demand for a cleaner bio-based fuel additive. Consequently, increasing quantities of by-products are generated by the ethanol industry for which markets need to be developed. The feed industry is a logical first choice to market these by-products.

1.2 Production of ethanol in North America

Ethanol production from cereal grains basically involves the conversion of starch into simple sugars through enzymatic hydrolysis and subsequent fermentation of the sugars into ethanol and CO_2 using the yeast *Saccharomyces sp.*

A variety of feedstocks can be fermented to produce ethanol. These feedstocks vary in the content of starch and thereby vary in potential ethanol yield (Table 1.1). The usual feedstocks include corn, wheat, barley, rye, and sorghum. Corn is the most common feedstock for ethanol production in North America due to its abundance and greater yield of ethanol compared to the other cereal grains (Aines et al. 1987). Wheat has been identified as the feedstock of choice for ethanol production in Canada, not only on the Canadian prairies but also in Ontario owing to its availability (Beaulieu and Goodyear 1985; Warren et al. 1994). Cultivation of corn for seed production is not possible in many areas of Canada (AAFC 2004). In Europe and in Australia, wheat is the major raw material for fuel ethanol production (Hunwick 1980; Swinnen et al. 1988).

Wheat is a more expensive feedstock than corn and feedstock accounts for 60 to 70% of ethanol production cost (Warren et al. 1994). Using wheat for fermentation, the ethanol yield was 340 litres MT^{-1} of feedstock or 510 to 710 litre ha^{-1} $year^{-1}$ (Dale 1991). Commercial yields range from 342 to 364 litre MT^{-1} of wheat (Sosulski and Sosulski 1994), depending on the type of wheat used for fermentation. Canada western prairie spring (CPS) wheat is preferred to hard red spring wheat, because CPS wheat contains a higher content of starch and lower content of protein (Lee et al. 1991) and might result in higher ethanol yields, e.g., 396 litre MT^{-1} with a by-product output of 266 kg MT^{-1}, on dry matter basis (Beaulieu and Goodyear 1985).

Table 1 Starch content and ethanol yield of various feedstocks

Feedstock	Moisture (%)	Starch (%)	Ethanol Yield (L MT^{-1})
Starch	-	100.0	720
Sugar	-	-	654
Barley	9.7	67.1	399
Corn	13.8	71.8	408
Oats	10.9	44.7	262
Wheat	10.9	63.8	375

Source: Saskatchewan Agriculture and Food (1993)

1.2.1 Milling processes for ethanol production

Two main milling procedures are employed in the production of ethanol from feedstock, wet milling and dry milling, followed by five basic steps within each procedure: feedstock handling and processing, saccharification, fermentation, distillation and, recovery and processing of by-products (NAS-NRC, 1981).

In the wet milling process, the grain is initially steeped by adding water to maximize the amount of starch removed from the kernel. In addition to water, sulphur dioxide is added in corn wet milling process to soften the grain, thereby disrupting the kernel in such a manner that oil and protein can be removed and a starch-enriched product for fermentation is generated. For wheat, the bran and germ are removed by dry milling in a flourmill prior to steep in water. Despite higher capital and energy costs with lower ethanol yield, the wet milling process dominates the ethanol industry due to the yield of purer starch and higher value by-products (Kane and Reilly 1989; Rendleman and Hohmann 1993; Chang et al. 1995).

In the dry milling process, the different components of the cereal grain are not fractionated (Rao 1979, Mulligan 1993), and the entire kernel of the grain is subjected to fermentation. Prior to water addition, the feedstock is cleaned and ground to reduce particle size, to facilitate enzymatic hydrolysis of starch to simple sugars. The entire dry milling process is outlined in Figure 1.1. The dry milling process is less popular than the wet milling process, representing approximately 40% of the market (Rendleman and Hohmann 1993). The dry milling process does not have a good potential for the production of high-value by-products, but has a cost advantage compared to wet milling.

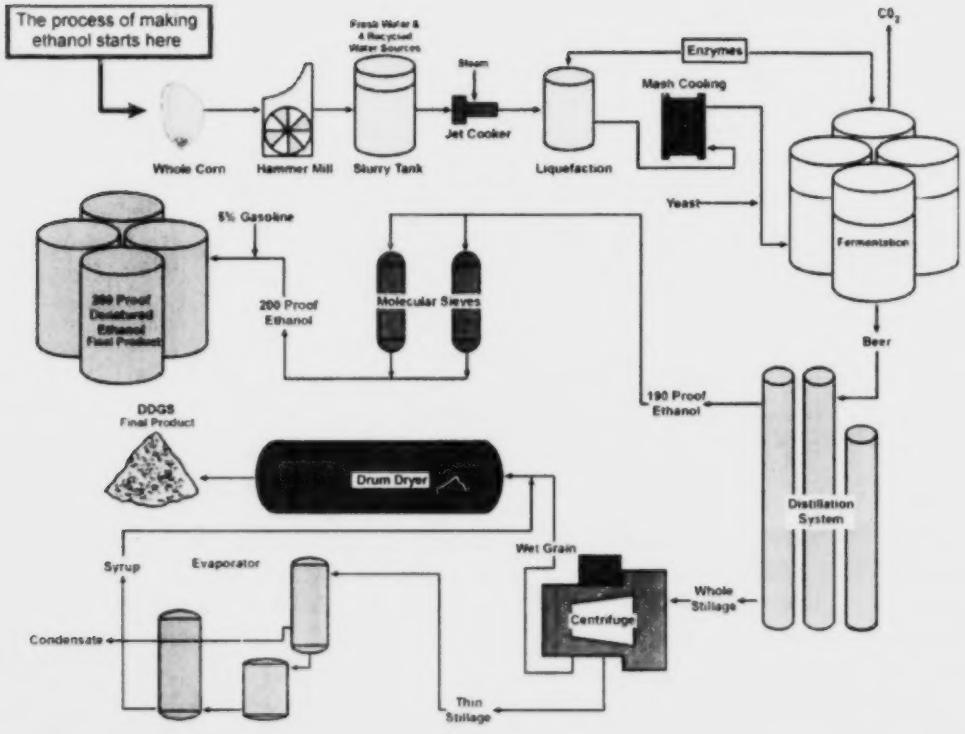

Figure 1 Dry milling ethanol production process (http://www.exolmn.com/process.htm)

1.2.2 Saccharification and fermentation processes

In saccharification, the starch portion of feedstock is prepared for yeast fermentation, converting the starch into simple sugars. Following water addition, enzymes are introduced to start the saccharification process. The saccharification process is 70 to 80% effective, regardless of the duration that the enzymes are allowed to act upon the grain starch (Weigel et al. 1997). The aim of saccharification is to obtain a solution containing 14 to 20% sugar (NAS-NRC, 1981).

The fermentation process begins with the introduction of selected yeasts. For fermentation, *Sacchromyces cerevisiae* is mainly used owing to their quick, efficient production of ethanol and their ability to survive in high alcohol concentrations (Weigel et al. 1997). One molecule of simple sugar yields two molecules of ethanol and two molecules of CO_2 during the fermentation process.

Two major methods of fermentation exist: batch and continuous. Using batch fermentation, a single batch of the mixture is fermented at one time and another batch cannot be started until the first batch is completed. In contrast, continuous fermentation involves a continuous flow of fermentation, upon constant addition of feedstock to the system. Batch fermentation is commonly used due to the ease of operation, low capital cost and the relatively easy processing

technique used. On the other hand, continuous fermentation has a high production capacity but the process control is more complex (Ingeldew 1993).

1.2.3 Distillation

The distillation process involves the separation of ethanol from the ethanol-water mixture by vaporizing ethanol at 78°C. The maximum ethanol concentration that is usually achieved through this process is 96%.

The remaining product is called whole stillage (McCurdy 1986), which contains everything that was not fermented and converted to ethanol and CO_2. Due to the utilization of the starch portion of the grain during the fermentation process, remaining nutrients such as protein, fat, fibre, vitamins and minerals undergo a three-fold concentration in whole stillage on dry matter basis (Newland and Mahan 1990; Mustafa et al. 1999). The dry matter content of the whole stillage is 5 to 7% and, the amount of dry matter depends on the type of grain used for fermentation, water-to-grain ratio, quantity and type of back set stillage used, the fermentation process, and the efficiency of utilization of sugar during fermentation (Salonek 1995). On a volume basis, the quantity of whole stillage produced is 10 to 15 times the amount of ethanol produced (Maiorella et al. 1983).

The whole stillage can be fractionated into approximately equal parts of the two by-products wet distiller's grains and thin stillage by centrifugation or screening (AAFC 2004). These by-products can be marketed in wet form or as dried products after drying (Larson et al. 1993; Ham et al. 1994). The centrifuged solid portion contains 25 to 35% dry matter, and can be dried as distiller's dried grains (DDG; Salonek 1995). The thin stillage represents the soluble portion and contains 4 to 9% dry matter (McKinnon et al. 1997). This portion can be condensed and dried by evaporation to obtain distiller's dried solubles (DDS).

1.2.4 Processing of by-products

The DDG and DDS can be marketed and included in livestock rations separately or as a combined product: distiller's dried grains with solubles (DDGS). Therefore, by-products from ethanol production are traditionally divided into three categories: DDG, DDS and DDGS (Newland and Mahan 1990). However, DDGS is presently the primary by-product and the production of the other two types is minimal. At least 75% of the solids of the resultant whole stillage should be condensed and dried for the product to be accepted as DDGS (Association of American Feed Control Officials). The annual production of DDGS in North America is approximately 3.2 to 3.5 million MT (Shurson et al. 2000). Corn and wheat thin stillage and distiller's grains have a different chemical composition (Table 1.2).

1.3 The use of by-products from ethanol industry in livestock rations

The nutritive value of by-products from ethanol production in dairy and beef cattle industry is well documented and has been reported for a number of by-products originated from a variety of feedstocks including corn (Larson et al. 1993; Ham et al. 1994; Lodge et al. 1997ab; Al-Suwaiegh et al. 2002), wheat (Fisher et al. 1999; Iwanchysko et al. 1999; Mustafa et al. 1999 & 2000), sorghum (Lodge et al. 1997a), barley (Mustafa et al. 1999 & 2000ab), and rye and

triticale (Mustafa et al. 2000b). The nutritional value for cattle has been evaluated using a variety of ethanol by-products including wet distiller's grains, thin stillage, DDG and DDGS.

Few studies have been conducted to investigate the nutritional value of by-products from ethanol industry for other species such as poultry (Manley et al. 1978; Maeda et al. 1982; Benabdeljelil and Jensen 1989; Cromwell et al. 1993; Martinez et al. 2004) and fish (Coyle et al. 2004). More than 80% of DDGS is included in ruminant diets, while less than 1% of the total annual production is used in swine diets (Shurson et al. 2000), although the latter inclusion portion is increasing rapidly.

Table 2 Chemical composition of corn and wheat based thin stillage and distiller's grains relative to original cereal grain (% DM)

Variable	Corn			Wheat		
	Grain	Thin stillage	Distiller's grains	Grain	Thin stillage	Distiller's grains
Crude protein	9-10	19.0	30.0	16.0	46.0	26.0
Crude fat	3-5	9.0	10.0	2.0	14.0	4.0
Ash	1-2	7.0	5.0	2.0	8.0	4.0
Acid detergent fibre	3.1	8.2	18.6	3.0	4.0	22.0
Neutral detergent fibre	10.8	27.0	43.0	16.0	34.0	74.0
Starch	70.0	25.0	8.0	63.0	2.0	2.0

Source: Mustafa et al. (2000) and NRC (1998)

1.3.1 The nutritional value of by-products from ethanol production for swine

In the early 1940's, the vitamin-rich DDS portion was the predominant by-product used in swine diets to supply B-vitamins and unidentified growth factors (Fairbanks et al. 1944). Currently, DDGS is the major distiller's feed used in swine diet formulations, representing over 95% of ethanol by-products (Newland and Mahan 1990).

However, the potential use of distiller's feeds in swine industry is not fully realized because of the scarcity of information on its nutritional value for swine. Product variability and lack of information about the nutritional value of DDGS from different sources are primary reasons for the reluctance of using corn DDGS in swine diets. Other concerns include, low AA digestibility (Wahlstrom et al. 1970) and an AA profile that is not well suited for pigs (Cromwell et al. 1983).

1.4 Chemical and physical characteristics of DDGS

Generally, the characteristics of DDGS depend mainly upon the type and quality of the cereal grain used for ethanol production. The nutrient composition of DDGS reflects the nutrient

content of original cereal grain, with a higher concentration of the remaining nutrient following starch removal (Sosulski and Tarasoff 1997; Weigel et al. 1997; Mustafa et al. 1999). In addition, yeast biomass used for fermentation contributes at least 3.9% of the weight of the DDGS (Ingeldew 1999). The composition of brewer's yeast *(Saccharomyces)* indicates that yeast may contribute a considerable portion of the nutrients present in DDGS (Table 1.3). For instance, at least 5.3% of DDGS protein is provided by the yeast protein (Ingledew 1999).

Due to the diversity of feedstocks that can be fermented to produce ethanol and the variation in nutrient composition within grain sources, nutrient levels of DDGS have been highly variable (Spiehs 2001). The nutrient variability of DDGS cannot be entirely avoided, because DDGS is a by-product of a process primarily aimed at ethanol production. The variability for any by-product is thus associated with DDGS as well. Conversely, DDGS is a combination of DDG and DDS, two by-products with different nutrient profiles (Table 1.2). Thus, any variation in each of the two by-products will affect nutrient composition of DDGS. As a result, nutrient variability is wider in DDGS than other cereal by-products. Method of fermentation, completeness or duration of the fermentation process, drying temperature and duration, and the ratio of DDS blended with DDG are other major factors associated with nutrient variability of DDGS (Carpenter 1970; Olentine 1986; Spiehs et al. 2002). Annual and regional differences in the cereal grain used for fermentation process appear to be a major reason for variation within processing plants. The nutrient composition of corn samples cultivated in the same region in five continuous years (from 1997 to 2001) and of DDGS produced from respective corn samples different significantly among these years (Belyea et al. 2004).

Colour and odour of DDGS are two important physical characteristics associated with nutritional value, because corn DDGS with golden yellow colour and sweet and slightly fermented odour is considered good quality while DDGS with dark brown colour and burnt or smoky odour is considered poor quality. Colour and odour are correlated with the nutritional properties of DDGS for monogastric animals (Cromwell et al. 1993).

Table 3 Approximate composition of brewer's *(Saccharomyces)* yeast

Variable	Content (g kg^{-1} dry yeast)
Carbohydrate	390 – 600
Protein	370 – 420
Ash	73 – 81
Phosphorus	14 – 20
Potassium	17
Sodium	0.7
Calcium	1.3
Iron	0.1
Magnesium	2.3
Cobalt	0.0002
Copper	0.033
Manganese	0.0057
Zinc	0.0387
Pantothenate	0.110 – 0.120
Choline	3.80 – 4.55
Thiamin (Vitamin B_1)	0.092 – 0.150
Riboflavin (Vitamin B_2)	0.035 – 0.045
Nicotinic acid/Niacin (NAD)	0.450
Pyridoxine (Vitamin B_6)	0.043 – 0.050
Biotin	0.001
Inositol	3.9 – 5.0
Folic acid	0.010

Source: Ingledew (1999)

1.4.1 Energy content and digestibility

Distiller's dried grains with solubles can be considered as a potential source of energy in livestock rations, based on its gross energy (GE) content. Nevertheless, this concept might be different for monogastrics due to the relatively high fibre content in DDGS, which may have limited the use of DDGS as an energy source in swine diets. However, the counteracting effect of a high fat content in DDGS results in a higher digestible energy (DE) value compared to that of the original cereal grain (Newland and Mahan 1990). The high fat content especially in corn DDGS, is associated with a higher gross energy content and therefore a higher DE content (Spiehs et al. 2002). The energy content varied considerably with the source and inclusion level of DDGS. The nutrient profile of corn DDGS originating from ten different ethanol plants varied widely in DE and metabolizable energy (ME) content (Spiehs et al. 2002). Specifically, DE content ranged from 3879 to 4084 kcal/kg and ME content ranged from 3639 to 3838 kcal/kg. Using three different inclusion levels of the same corn DDGS sample (10, 20 and 30%), grower-finisher pigs revealed the variability of DE and ME content (Spiehs et al. 2000). Specifically, the DE content ranged from 2830 to 5862 kcal/kg and the ME content ranged from 2551 to 5827 kcal/kg, indicating the difficulty of using book values for DE and ME content of DDGS in swine ration formulation.

The variability in DE and ME content of DDGS among different sources and inclusion rates is partially a reflection from variability in energy digestibility. The non-starch polysaccharides (NSP) are concentrated with other nutrients in DDGS after most of the starch in the cereal grain is removed during fermentation (Mustafa et al. 1999). An increased level of NSP in DDGS may reduce energy digestibility because the NSP fractions may hinder the action of digestive enzymes in the small intestine and affect microbial activity thus, interfering the digestion process (van Barneveld et al. 1995; Grieshop et al. 2001).

1.4.2 Protein and amino acid content and digestibility

Few studies have been conducted during the last few years using corn DDGS in swine nutrition. Therefore, currently available AA composition and digestibility values are mainly based on studies conducted by Wahlstrom et al. (1980), Cromwell et al. (1983), and Cromwell and Stahly (1986).

Based on the relatively high crude protein content, DDGS can be considered as a potential source of supplemental protein and AA for swine. Nevertheless, the protein quality of DDGS is low due to deficiency of several indispensable AA, including lysine and tryptophan (Newland and Mahan 1990). Furthermore, corn DDGS samples originating from various sources may vary considerably in crude protein and AA composition (Cromwell et al. 1993; Spiehs et al. 2002). Initially, lysine was the most variable of the eleven AA analysed in the nine samples (Cromwell et al. 1993). Likewise a decade later, of the ten indispensable AA analyzed in the ten samples from different ethanol plants, lysine was the most variable, with a CV ranging from 2.9 to 25.7%, followed by methionine (Spiehs et al. 2002). Lysine and Methionine contents varied from 0.72 to 1.02 and from 0.49 to 0.69% (dry matter basis), respectively.

The AA profile of DDGS is not well-suited for pigs (Cromwell et al. 1983). The lack of lysine, the first limiting AA in swine nutrition, is particularly critical. Some of the lysine is destroyed during the fermentation and/or drying processes of DDGS. Following overheating, lysine forms complexes with carbonyl groups, the Maillard reaction, which are associated with a colour change and stimulated by heat in the presence of moisture, the exact conditions present in

the drying process (Patience et al. 1995). The relatively low total lysine content in DDGS suggests the occurrence of similar type processes with overheating of DDGS samples.

The DDGS has a lower AA digestibility than cereal ingredients in swine (Wahlstrom et al. 1970). Similar to energy digestibility, the NSP fraction of DDGS may affect the digestion process of AA as well (van Barneveld et al. 1995: Groeshop et al. 2001). The negative effects of NSP on DM, energy and AA digestibility have been well described (Kennelly and Aherne 1980; Fairbairn et al. 1999; Zijlstra et al. 1999; de Lange 2000; de Lange et al. 2000; Jondreville et al. 2001; Yin et al. 2002). Based on the high fibre content of DDGS, plausible factors contributing to low AA digestibility in DDGS could be: decreased enzymatic breakdown of dietary protein, thereby reduced absorption and increased undigested protein (AA) in digesta, increased endogenous AA losses (Jondreville et al. 2001) and binding of AA and peptides to fibre (Bergner et al. 1981, as referenced by Lenis et al. 1996).

1.4.3 Phosphorus content and availability

The bioavailability of P was enhanced in DDGS due to fermentation during which phytate-P was hydrolyzed by microbial phytase (Singsen et al. 1972 as referenced by Cromwell 1979). Approximately 60 to 70% of the total P in a cereal-based diet is bound to phytate, and this phytate-P is unavailable to the pig (Baker 1991). The indigestible P is excreted in faeces, and may impact the environment negatively if not managed properly (Cromwell et al. 1993; Liu et al 1998; NRC 1998). On the other hand, P is a mineral of particular interest because it is the third most expensive nutrient after energy and protein (NRC 1998). A higher content and digestibility of P in DDGS compared to cereals may indicate environmental and economical benefits of DDGS for the management of P in swine diets and manure.

1.5 The use of distiller's dried grains with solubles in swine industry

The use of corn DDGS in swine rations has been tested with different inclusion rates in pigs of different growth stages including starter pigs (Combs and Wallace 1969; Richards 1979; Wahlstrom and Libal 1980; Orr et al. 1981; Cromwell et al. 1985; Miller et al. 1987), grower-finisher pigs (Livingstone and Livingston 1966; Wahlstrom and German 1968; Walstrom and Libal 1969; Wahlstrom et al. 1970; Combs and Wallace 1970; Smelski and Stothers 1970; Harmon 1975; Cromwell et al. 1983; Cromwell et al. 1984; Cromwell et al. 1986; Cromwell et al. 1993), and breeding stock (Thong et al. 1978). Some studies evaluated the AA profile of DDGS and investigated the effect of lysine supplementation on performance of pigs fed DDGS incorporated diets (Wahlstrom et al. 1970; Cromwell et al. 1983; Cromwell and Stahly 1986). Possibilities of alleviating the negative effects associated with DDGS on growth performance of weanling pigs were studied by adding antibiotics to the diet and observed better performance with diets with antibiotics (Cromwell et al. 1985). More recently, description of the nutritional value of corn DDGS for swine has gained renewed attention (Shurson et al. 2000; Spiehs 2001; Spiehs et al. 2002; Whitney and Shurson 2004). Nevertheless, information on the use of wheat DDGS in swine nutrition remains scarce. The effects of different levels of corn DDGS on growth performance of pigs in different growth stages are summarized in Tables 1.4, 1.5 and 1.6.

Table 4 Effect of graded levels of corn distiller's dried grains with solubles in corn-soybean meal diets on growth performance of starter pigs.

Study	DDGS (%)	ADG (kg)		ADFI (kg)		Feed Efficiency	
		Control	DDGS	Control	DDGS	Control	DDGS
Combs and Wallace 1969	10	0.58	0.61	1.25	1.39	2.16	2.26
	20	0.58	0.60	1.25	1.37	2.16	2.29
Wahlstrom and Libal 1980	10	0.35	0.34	0.61	0.61	1.75	1.82
	20	0.35	0.32	0.61	0.58	1.75	1.84
	30	0.35	0.29	0.61	0.56	1.75	1.90
Orr et al. 1981	2.5	0.27	0.30	0.47	0.50	1.74	1.65
	5.0	0.27	0.27	0.47	0.46	1.74	1.74
Cromwell et al. 1985	10	0.63	0.60	1.26	1.28	2.01	2.13
	10*	0.63	0.66	1.27	1.35	1.99	2.05

* experimental diets with an antibiotic

Table 5 Effect of different levels of corn distiller's dried grains with solubles on reproductive performance of sows

Variable	Distiller's dried grain with solubles (%)		
	0	17.7	44.2
Live pigs born	8.8	8.6	8.2
Birth weight (kg)	1.4	1.4	1.4
Pigs weaned (28 d)	7.3	7.4	7.3
Weaning weight (kg)	6.5	6.7	6.6
Feed intake in lactation (kg)	123	105	112
Sow weight loss in lactation (kg)	5.3	3.9	1.4

Source, Thong et al. (1978)

Table 6 Effect of graded levels of corn distiller's dried grains with solubles on growth performance of grower-finisher pigs.

Study	DDGS (%)	ADG (kg)		ADFI (kg)		Feed efficiency	
		Control	DDGS	Control	DDGS	Control	DDGS

Livingstone and Livinston 1966[a]	14.7	0.63	0.64	NR	NR	3.38	3.34
	25.0	0.63	0.58	NR	NR	3.38	3.56
Wahlstrom et al. 1970[b]	5.0	0.78	0.81	2.52	2.58	3.21	3.20
	10.0	0.78	0.78	2.52	2.46	3.21	3.17
	20.0	0.78	0.75	2.52	2.69	3.21	3.59
Wahlstrom et al. 1970[c]	5.0	0.77	0.76	2.30	2.15	2.97	2.82
	10.0	0.77	0.77	2.30	2.11	2.97	2.73
	20.0	0.77	0.73	2.30	2.09	2.97	2.89
Combs and Wallace 1970[b]	10.0	0.83	0.82	2.66	2.85	3.22	3.48
	20.0	0.83	0.86	2.66	3.02	3.22	3.56
Smelski and Stothers 1972[d]	7.5	0.75	0.74	2.75	2.70	3.71	3.65
	15.0	0.75	0.70	2.75	2.70	3.71	3.86
Cromwell et al. 1983[b]	5.0	0.80	0.88	2.69	2.87	3.35	3.28
	10.0	0.80	0.83	2.69	2.79	3.35	3.36
	20.0	0.80	0.79	2.69	2.74	3.35	3.47
	40.0	0.80	0.76	2.69	2.80	3.35	3.70
Cromwell et al. 1984[b]	2.5	0.83	0.83	2.59	2.61	3.12	3.14
	5.0	0.83	0.83	2.59	2.59	3.12	3.12
	10.0	0.83	0.82	2.59	2.53	3.12	3.09
Cromwell et al. 1986[b]	10.0	0.84	0.85	2.75	2.77	3.25	3.26

NR - not reported

[a] Barley, wheat, soybean meal basal diet

[b] Corn, soybean meal basal diet without synthetic lysine supplementation

[c] Corn, soybean meal basal diet with synthetic lysine supplementation

[d] Barley, soybean meal basal diet with synthetic lysine supplementation

1.5.1 Effect on voluntary feed intake

Voluntary feed intake (VFI) may be reduced when corn DDGS is included in swine diets (Wahlstrom and Libal 1980; Whitney and Shurson 2004). Reasons for the reduction in VFI remain unclear and dietary inclusion of DDGS seemed to negatively affect palatability (Whitney and Shurson 2004), probably due to high fibre content. Factors, which are unfavourable for the

palatability and feed intake, such as mold spores, can be concentrated in DDGS, during fermentation. Other possibilities causing a reduced VFI include a significant AA imbalance, including an increased level of non-essential AA [(NEAA) Henry et al. 1992; Henry 1995; Hahn et al. 1995] and high energy density due to relatively high fat content of DDGS (Azain 2001). An increased level of NSP will increase fermentation in the hind gut of pigs (Govers et al. 1999). Oligosaccharides are generally undigested in the small intestine but are highly fermentable in the hindgut (Wigan et al. 1994). The increased hindgut fermentation might reduce VFI through physically distending the colon, thereby increasing the retention time (Cherbut et al. 1988).

1.5.2 Effect on growth performance

The appropriate inclusion levels of DDGS at different growth stages have received considerable debate. In starter pigs, growth performance was unaffected at levels up to 10% DDGS in a basal diet of corn-soybean meal (Combs and Wallace 1969; Wahlstrom and Libal 1980), suppressed at the level of 10% DDGS in the diet (Cromwell et al. 1985), or increased numerically with 2.5% DDGS in a basal diet of corn-soybean meal without additional benefits at 5% DDGS (Orr et al. 1981). Nevertheless, DDGS was incorporated successfully at levels up to 5% into starter pig feeding programs (Richards 1979).

The DDGS was incorporated as an alternate protein and energy source at levels up to 10% of grower-finisher pig diets without adversely affecting growth performance (Wahlstrom and German 1968; Cromwell et al. 1984; Cromwell et al. 1985). However, performance of grower-finisher pigs was variable at higher DDGS inclusion levels. In some studies, performance in grower-finisher pigs fed diets containing 20% DDGS was equal to the pigs fed corn-soybean meal basal diets (Harmon 1975; Cromwell et al. 1983). However, performance was reduced in grower-finisher pigs fed diets containing 20% DDGS in another study (Wahlstrom and Libal 1969). Higher inclusion levels of DDGS (30 and 40%) in the diets of grower-finisher pigs adversely affected the growth (Cromwell et al. 1983).

In sows, DDGS might have less negative effects on performance. Corn DDGS was included at levels up to 44.2% in a corn-soybean meal diet without affecting reproductive performance (Thong et al. 1978; Table 1.6). Litter size, average birth weight of pigs, number of pigs weaned per litter and average weaning weight of pigs did not differ among treatments. In addition, feed intake of lactation sows, body weight gains and losses of gestation and lactation sows, respectively, were similar among the dietary treatments.

Inclusion of DDGS increases dietary CP content with a simultaneous increase of NEAA, because DDGS is high in CP and has an improperly balanced AA profile. An increased supply of AA will increase AA absorption in excess of AA requirement for maintenance and protein synthesis. The excess AA are catabolized and the NH_3 generated as a result of deamination is eliminated from the body via the kidney as urea in urine. Accordingly, feeding pigs diets containing DDGS increases N excretion, thereby increasing the requirement of metabolic energy for AA catabolism and urea synthesis, leaving less available energy to support production functions (Spiehs et al. 2002). On the other hand, the dietary lysine intake may comparatively low for pigs fed diets containing DDGS, mainly due to lower feed intake and lower total lysine content in DDGS, which together with lower lysine availability of DDGS may constrain protein accretion of pigs. The relationship between lysine intake and growth performance of grower-finisher pigs is well-documented (Henry et al. 1988; Chiba et al. 1991; Friesen et al. 1994) and

variability in growth performance of pigs fed DDGS incorporated diets can partly be attributed to the differences in lysine intake as well as availability.

1.5.3 Impact on nutrient excretion

Nitrogen intake will be relatively high in pigs fed DDGS diets owing to the higher crude protein content in DDGS. The increase in N intake will increase in N excretion in faeces and urine, and the improperly-balanced AA profile in DDGS may further increase the N excretion of pigs, because about 50% of N excretion in pig manure can be attributed to the poor AA balance in the diet (de Lange 2004).

Dietary fermentable fibre may shift N excretion from urea in urine to bacterial protein in faeces (Morgan and Whittemore 1988; Mroz et al. 1993; Lenis et al. 1996; Canh et al. 1997; Canh et al. 1998; Zervas and Zijlstra 2002). The bacterial N assimilation with the presence of fermentable NSP in the hindgut is the underlying reason for this phenomenon. Therefore, a shift of N excretion from urine to faeces can be expected with the inclusion of DDGS in the diet due to the concentrated NSP fraction of DDGS. In addition, reduced AA digestibility caused by the NSP can be considered as another factor associated with N excretion patterns. Environmentally, faecal N is preferable to urinary N, because faecal N (mainly bacterial protein) is less susceptible to rapid decomposition than urinary N (mainly urea), which is easily converted into ammonium and CO_2 by faecal urease (Canh et al. 1998b; Mroz et al. 2000).

The content of non-phytate P is higher in DDGS than in the unfermented starting material due to the fermentation during which phytate-P was hydrolyzed by microbial phytase (Singsen et al. 1972: as referenced by Cromwell 1979), and consequently P digestibility or availability is higher. Therefore, based on higher unbound P content in DDGS, a high intake of digestible P can be expected for pigs fed DDGS diets. Increased amount of P appears in faeces and urine, as a consequence of increased P intake (Cromwell et al. 1993; Jongbloed et al. 1993; Liu et al. 1998; Ekpe et al. 2002). The P excretion in swine mainly occurs in faeces, and increased P excretion in faeces with increasing levels of digestible P intake can be expected (Ekpe et al. 2002; Zhang et al. 2003). A portion of P excreted by pig is a direct result of feeding excessive levels of digestible P (Ekpe et al. 2002). Therefore, P excretion in the swine industry can be managed by dietary manipulation and supplemental inorganic P can be reduced when DDGS is incorporated into the diet. Reducing total P content may reduce feed costs, thereby increasing net income. The strategy indicates environmental and economical benefits of DDGS for the management of P in swine diets and manure.

1.6 Potential to enhance the nutritional value of distiller's dried grains with solubles

Many feed ingredients, including cereals and their by-products, contain considerable amounts of anti-nutritional factors (ANF), which affect the nutritional value of those ingredients when fed to monogastrics. In recent years, concerted efforts to enhance the nutritional value of such feedstuffs have been undertaken to maximize nutrient utilization. The use of exogenous enzymes has been recognized as one of the ways to improve nutrient utilization. Apart from improved nutrient utilization from feedstuffs, the quality of the environment might be improved by reducing the manure output and pollution associated with manure (Classen 1998).

1.6.1 The use of exogenous enzymes in livestock industry

Several possible mechanisms have been proposed to explain the beneficial effects of the use of exogenous enzymes in livestock industry: (1) removal of anti-nutritional factors (ANF); (2) increasing the digestibility of existing nutrients; (3) increasing the digestibility of NSP; and (4) supplementing host endogenous enzymes (Classen et al. 1991). Nevertheless, the current primary objective of the use of exogenous enzymes in commercial livestock rations is the potential degradation of NSP or phytic acid to maximize the nutrient utilization from feedstuffs.

1.6.2 Non-starch polysaccharides

The cell walls of cereal grains are primarily comprised of complex carbohydrates referred to as NSP (Choct 1997), and consist predominantly of β–glucans in barley and oats, and arabinoxylan in wheat, rye and triticale (Englyst et al. 1989; Bach Knudsen 1997; Zijlstra et al. 1999). The β-glucans consist of linear chains of β-glycosyl residues linked by β (1-3) or (1-4) bonds with predominant (1-4) linkages (MacGregor and Fincher 1993). Arabinoxylans, on the other hand, are a β (1-4) linked polymers of the pentoses arabinose and xylose, and are hence referred to as pentosans (Fincher and Stone 1986).

The predominant NSP in cell walls varies among cereal grains. Furthermore, the content of NSP varies widely among cereals, with barley and hullless barley containing more NSP than wheat or corn (Fincher and Stone 1986). Finally, the NSP content varies among samples of barley (Fairbairn et al. 1999), wheat (Zijlstra et al. 1999) and hullless barley (Andersson et al. 1999). Not only grain type and cultivar but also the rate of fertilization and growing conditions may affect the NSP content within a crop year (Oscarsson et al. 1998).

The NSP fraction of cereal grains has drawn a considerable attention in poultry and swine ration formulation, because the digestive system of monogastrics lacks the appropriate endogenous enzymes required to hydrolyse NSP. In poultry, NSP associated digesta viscosity is mainly responsible for the reduced nutrient utilization and growth performance (Choct and Annison 1992; Almirall et al. 1995). Nevertheless, viscosity-altering properties of NSP are not as likely to be an issue of the same magnitude in swine nutrition (Bedford et al. 1992; Johansen et al. 1997; Pluske et al. 1999; Mavromichalis et al. 2000; Medel et al. 2002; Högberg and Lindberg 2004; Zijlstra et al. 2004). Rather, as a physical barrier, interferences of NSP with the action of digestive enzymes and digestion process are more important (van Barneveld et al. 1995; Grieshop et al. 2001). The negative correlation between the energy digestibility and the dietary content of NSP is well-documented (Fairbairn et al. 1999; Zijlstra et al. 1999; de Lange et al. 2000; Yin et al. 2002).

In swine, apparent total-tract NSP digestibility is higher than apparent ileal digestibility, due to microbial degradation in the hindgut (Li et al. 1996). From a nutrient utilization point of view, however, nutrients absorbed after fermentation in the large intestine have less nutritional value for pigs than nutrients absorbed in the small intestine after digestion with endogenous digestive enzymes (Noblet et al. 1994; Fuller and Reeds 1998; Noblet 1999). Moreover, the net energy value of carbohydrates fermented and absorbed as volatile fatty acids in the large intestine of pig is 30% lower than that from the small intestine (Dierick et al. 1989).

1.6.3 Carbohydrase supplementation of livestock rations

Enzyme preparations have been formulated to facilitate the digestion process of NSP in monogastrics, prior to fermentation in the large intestine. These enzymes are commonly referred to as carbohydrases. The main carbohydrases used in livestock rations to alleviate the detrimental effects associated with NSP are xylanase and β-glucanase. The effects of carbohydrases on nutrient digestibility and growth performance at different growth stages of non-ruminants, using either xylanase or β-glucanase in poultry and swine diets have been studied in depth. In addition, both carbohydrases combined have been studied (Thacker et al. 1992a; Inborr et al. 1993; Yin et al. 2001a,b; Högberg and Lindberg 2004; Zijlstra et al. 2004; Thacker and Rossnagel 2005), making definitions of relationships between specific activities and beneficial effects difficult. Interestingly, the influence of these supplemental enzymes, mostly in combination with other fibrolytic enzymes, has also been studied in ruminants, despite the fibre degradation ability of microorganisms in the rumen (ZoBell et al. 2000; Bowman et al. 2002; Kung et al. 2002; Colombatto et al. 2003; Nowak et al. 2003; Yu et al. 2005).

Experiments with swine however, often demonstrated inconsistent responses to xylanase supplementation, only some studies showing an improvement in nutrient digestibility (Rattay et al. 1998; Yin et al. 2000; Barrera et al. 2004) and growth performance (Van Lunen and Schulze 1996; Barrera et al. 2004), while the other experiments concluding with a lack of response either in nutrient digestibility (Thacker et al. 1991; Bedford et al. 1992; Mavromichalis et al 2000; Yin et al. 2001b; Diebold et al. 2005) or performance (Bedford et al. 1992; Inborr et al. 1993; Mavromichalis et al 2000).

1.6.4 Carbohydrase supplementation of swine rations

Numerous attempts have been made to maximize nutrient digestibility and hence improve the performance of pigs fed diets based on cereal grains supplemented with exogenous carbohydrases. Nevertheless, most of these studies have not been successful in demonstrating improvements in performance of a magnitude similar to those observed in poultry for either starter pigs (Baird et al. 1976; Inborr and Ogle 1988; Officer 1991; Thacker et al. 1992b; Inborr et al. 1993; Baidoo et al. 1998; Jensen et al. 1998; Li et al. 1999; Mavromichalis et al. 2000; Högberg and Lindberg 2004) or grower-finisher pigs (Newman et al. 1980, 1983; Honeyfield and Froseth 1984; Cromwell 1989; Thacker et al. 1989; Thacker et al. 1992a, 1992b; Baas and Thacker 1996; Thacker and Campbell 1999; Mavromichalis et al. 2000; Thacker and Rossnagel 2005). Effects of carbohydrases on nutrient digestibility and growth performance in different growth stages of pigs are summarized in Tables 1.7 and 1.8, respectively.

Recently, the suppressive effect of NSP on VFI received attention. A positive quadratic dose-response correlation existed between ADFI and ADG upon carbohydrase supplementation of starter pig diets, indicating that carbohydrase will improve VFI, but suggest that an excess breakdown of the respective NSP in the gastro-intestinal tract may thereafter directly or indirectly inhibit voluntary feed intake (Zijlstra et al. 2004).

Supplemental carbohydrases have been tested for their ability to improve nutrient digestibility in swine. A number of previous studies reported no improvement in nutrient digestibility either in starter (Bedford et al. 1992; Thacker et al. 1992b; Li et al. 1996b; Mavromichalis et al. 2000; Högberg and Lindberg 2004; Zijlstra et al. 2004; Diebold et al. 2005) or grower-finisher pigs (Graham et al. 1986, 1989; Thacker et al. 1989; Thacker et al. 1992a, 1992b; Li et al. 1996a; Mavromichalis et al. 2000). Under normal conditions and with good

quality cereal ingredients, beneficial effects of carbohydrases on nutrient digestibility and growth performance might therefore be difficult to obtain.

Table 7 Effect of carbohydrases on nutrient digestibility (%) in different age groups of pigs

Study	Dry matter		Energy		Crude protein	
	Control	Enzyme	Control	Enzyme	Control	Enzyme
Starter pigs						
Thacker et al. 1992b[z]	83.7	83.1	82.6	81.9	78.4	77.8
Baidoo et al. 1998[y]						
Apparent ileal	56.0[b]	64.5[a]	57.1[b]	63.3[a]	57.6	61.8
Total tract	76.1	80.3	75.0	79.4	66.2	72.0
Mavromichalis et al. 2000[x]	87.2	87.8	NR	NR	86.9	88.0
Grower-finisher pigs						
Thacker et al. 1992a[v]	75.8	76.4	74.2	75.6	72.2	73.7
Thacker et al. 1992a[u]	81.2	82.6	72.5	76.5	78.9	80.6
Thacker et al. 1992b[t]	76.2[b]	80.6[a]	76.3	79.3	78.6	75.3
Mavromichalis et al. 2000[x]	84.7	86.0	NR	NR	81.9	84.8
Thacker and Rossnagel 2004[s]	79.0	79.6	78.4	78.8	77.9	79.7
Thacker and Rossnagel 2004[r]	72.5	74.7	72.8	74.8	79.1	81.4
Thacker and Rossnagel 2004[q]	73.1	74.3	73.8	75.1	79.3	80.8

NR - not reported

[z] Hulless barley - SBM based diets with β-glucanase

[y] Hulless barley based diets with a combination of xylanase and β-glucanase

[x] Wheat soybean meal based diets with xylanase

[s] Barley - SBM based diets with a combination of xylanase and β-glucanase

[q] Rye - SBM based diets with a combination of xylanase and β-glucanase

[t] Barley - SBM based diets with β-glucanase

[s] Barley - SBM based diets with a combination of xylanase and β-glucanase

[r] Normal oat - SBM based diets with a combination of xylanase and β-glucanase

[q] High fat oat - SBM based diets with a combination of xylanase and β-glucanase

Table 8 Effect of carbohydrases on growth performance in different age groups of pigs

Study	ADG (g)		ADFI (g)		Feed efficiency	
	Control	Enzyme	Control	Enzyme	Control	Enzyme
Starter pigs						
Thacker et al. 1992b[z]	254	274	534	547	2.20	2.03
Baidoo et al. 1998[y]	462	511	651	700	1.41	1.37
Mavromichalis et al. 2000[x]	450	470	520	570	1.15	1.22
Högberg and Lindberg 2004[w]	195	198	295	304	1.51	1.53
Grower-finisher pigs						
Thacker et al. 1992a[v]	840	860	2140	2220	2.53	2.59
Thacker et al. 1992a[u]	740	710	1770	1750	2.40	2.48
Thacker et al. 1992b[t]	830	840	2560	2470	3.09	3.04
Baidoo et al. 1998[y]	985	1025	2315	2122	2.35	2.07
Mavromichalis et al. 2000[x]	900	930	2910	2990	3.23	3.23
Thacker and Rossnagel 2004[s]	1020	1060	2670	2690	2.62	2.54
Thacker and Rossnagel 2004[r]	1050	1030	2740	2770	2.60	2.70
Thacker and Rossnagel 2004[q]	1060	1040	2710	2660	2.57	2.57

[z] Hulless barley - SBM based diets with β-glucanase

[y] Hulless barley based diets with a combination of xylanase and β-glucanase

[x] Wheat soybean meal based diets with xylanase

[w] Diets with a combination of xylanase and β-glucanase contained barley, oats, triticale, wheat and wheat bran

[v] Barley - SBM based diets with a combination of xylanase and β-glucanase

[u] Rye - SBM based diets with a combination of xylanase and β-glucanase

[t] Barley - SBM based diets with β-glucanase

[s] Barley - SBM based diets with a combination of xylanase and β-glucanase

[r] Normal oat - SBM based diets with a combination of xylanase and β-glucanase

[q] High fat oat - SBM based diets with a combination of xylanase and β-glucanase

1.6.5 Xylanase supplementation of swine rations

A considerable amount of research with carbohydrases has been conducted using supplementary xylanase, which is generally used in wheat-based diets. Nevertheless, studies to evaluate the effect of supplementary xylanase on nutrient digestibility and performance in wheat-based diets for swine are limited and controversial.

While a number of studies reported a beneficial effects of xylanase on pig growth performance (Dierick 1989; Van Lunen and Schulze 1996; Barrera et al. 2004; Zijlstra et al. 2004), other studies reported no significant effects (Thacker et al. 1991, 1992a; Bedford et al. 1992; Inborr et al. 1993; Thacker and Bass 1996; Högberg and Lindberg 2004; Thacker and Rossnagel 2005). Inconsistent results have also been reported among weight categories of swine. For example, xylanase supplementation did not affect performance in nursery pigs and in one of two experiments with finisher pigs fed wheat-based diets; however, xylanase improved performance in the second experiment with finisher pigs (Mavromichalis et al. 2000). Similarly, supplemental xylanase affected nutrient digestibility in pigs inconsistently. Sometimes xylanase improved digestibility (Graham et al. 1988; Baidoo et al. 1998; Rattay et al. 1998; Yin et al. 2000b; Barrera et al. 2004; Thacker and Rossnagel 2005), while nutrient digestibility of pigs also sometimes did not improve with supplementary xylanase (Thacker et al. 1991, 1992a; Bedford et al. 1992; Mavromichalis et al. 2000; Yin et al. 2001; Högberg and Lindberg 2004; Zijlstra et al. 2004; Diebold et al. 2005).

One unit (U) of xylanase activity is defined as the amount of enzyme required to release 1 mol of reducing sugars (expressed as xylose) in 1 min (Tervila-Wila et al. 1996). Xylanase supplementation at rates of 5500, 11,000 and 16,500 U kg^{-1} improved nutrient digestibility and some performance variables linearly and quadratically ingrower pigs fed wheat-based diets, with the best response with the intermediate inclusion level of xylanase (11,000 U kg^{-1}; Barrera et al. 2004). In another experiment conducted using finishing pigs fed wheat-based diets in mash and pellet forms supplemented with two different forms of xylanase, powder and liquid with 4000 and 8000 U g^{-1} xylanase activity, respectively, xylanase improved growth performance and nutrient digestibility in pigs fed mash diets but not in pigs fed pelleted diets (Park et al. 2003). Inconsistency in growth performance and nutrient digestibility in pigs fed diets with supplementary xylanase can therefore attributed to the factors such as growth stage of pigs, level of xylanase and the nature of the diet.

1.6.5.1 Effect on energy digestibility

Xylanase supplementation has improved energy digestibility in some studies, whereas the rest of the studies lacked a beneficial of response. The inconsistency can be attributed to variations among the major ingredients in NSP content, the level of supplementary xylanase and the age of experimental pigs.

Supplemental xylanase in diets based on wheat and its by-products improved ileal and total-tract apparent energy digestibility 3 and 1%, respectively, in grower pigs (Yin et al. 2000b). In weanling pigs, xylanase supplementation in combination with β-glucanase of diets based on hull-less barley improved both apparent ileal and total-tract digestibility of energy 11 and 6%, respectively (Baidoo et al. 1998) and of diets based on barley and pollard, improved the apparent ileal digestibility of energy 4%, without affecting total-tract digestibility (Graham et al. 1988). In addition, the same enzyme combination improved the total tract digestibility of energy in grower-finisher pigs fed diets containing normal or high fat oat (Thacker and Rossnagel 2005).

In contrast, xylanase supplementation on meal and pellet form rye-based diets did not improve total tract energy digestibility in weanling pigs (Thacker et al. 1991). Similarly, supplementing xylanase to diets based on hulless barley or wheat did not improve either apparent ileal or total tract energy digestibility in young or weaner pigs, respectively (Yin et al. 2001b; Diebold et al. 2005). Supplementing diets based on barley, wheat, oats, triticale and wheat bran with xylanase together with β-glucanase did not affect total tract digestibility of energy in weaned piglets (Högberg and Lindberg 2004). The same enzyme combination at different inclusion rates in a diet based on wheat and canola meal did not affect apparent digestibility of energy in each of the four segments of the small intestine examined in weaned pigs (Zijlstra et al. 2004). Moreover, xylanase in combination with β-glucanase did not influence total tract energy digestibility of growing or finishing pigs fed diets based on barley or rye (Thacker et al. 1992a). Interestingly, xylanase together with β-glucanase did not affect the total tract energy digestibility in grower pigs fed diets containing barley, wheat, SBM and low-mucilage canola meal, but improved the digestibility coefficient in pigs fed the same diet, replacing low-mucilage canola meal with Candle canola meal (Bell and Keith 1989). Combined, the data indicate that effects of xylanase on energy digestibility are dose dependent and may depend on the amount of arabinoxylans in the diet and whether the arabinoxylans are indeed a factor limiting energy digestibility in the specific diet.

1.6.5.2 Effect on protein and amino acid digestibility

Beneficial effects of xylanase supplementation on protein and AA digestibility in swine have been observed. With the increase in the rate of xylanase supplementation, apparent ileal digestibility of CP and AA improved linearly and quadratically in grower pigs fed wheat-based diets, achieving the highest digestibility values in diets supplemented with 11,000 U g^{-1} enzyme activity, improving CP digestibility 7% (Barrera et al. 2004). Supplementation of a diet containing barley, wheat, wheat bran and SBM with xylanase improved apparent ileal digestibility of CP in growing pigs 5% (Rattay et al. 1998). Furthermore, supplemental xylanase in diets based on wheat or its by-products improved apparent ileal digestibility of some of the indispensable AA and of CP 2% and total tract digestibility of CP 1% in grower pigs (Yin et al. 2000b). Supplementary xylanase in combination with β-glucanase in two diets, each containing one of two varieties of hull-less barley improved both apparent ileal and total tract digestibility of CP 8 and 9%, respectively, and apparent ileal digestibility of all AA in both diets (Baidoo et al. 1998). In addition, supplementing xylanase together with β-glucanase, improved the apparent ileal digestibility of CP 7%, without affecting total tract digestibility, in weanling pigs fed diets based on barley and pollard (Graham et al. 1988). The same enzyme combination improved the total tract digestibility of CP in grower-finisher pigs fed diets containing normal or high fat oat (Thacker and Rossnagel 2005). However, supplementing xylanase to rye-based diets in meal and pellet forms did not improve the total tract CP digestibility in weanling pigs (Thacker et al. 1991). In addition, supplementary xylanase in rye-based diets did not show any improvement in CP (N) digestibility in weanling pigs (Bedford et al. 1992). Likewise, xylanase supplementation to diets based on wheat did not affect apparent lieal or total tract digestibility of CP or ileal digestibility of AA in weaner pigs (Diebold et al. 2005) and total tract digestibility of CP (N) in nursery and finishing pigs (Mavromichalis et al 2000). Supplementary xylanase in combination with β-glucanase had no influence on CP digestibility at any site of the digestive tract of weaned piglets fed diets based on main cereals and wheat bran (Högberg and Lindberg 2004). The same enzyme combination did not influence the total tract CP digestibility of growing or finishing pigs

fed diets based on barley or rye, respectively (Thacker et al. 1992a), or of growing pigs fed diets containing barley, wheat and SBM with either low-mucilage or candle canola meal (Bell and Keith 1989). In addition, supplementing hull-less barley-based diets with xylanase did not affect apparent ileal or total tract digestibility of CP in young pigs, but improved apparent ileal digestibility of most of indispensable and dispensable AA (Yin et al. 2001).

As was the case for energy digestibility, plausible factors contributing to the inconsistency in AA and CP digestibility among studies might be the variations in substrate level of ingredients used, the level of supplementary xylanase added and the variations in genetic potential and age of experimental pigs. Collectively, the data indicate that effects of xylanase on protein and AA digestibility are dose dependent and may depend of the amount of arabinoxylans in the diet and whether the arabinoxylans are indeed a factor limiting protein and AA energy digestibility in the specific diet.

1.6.5.3 Effect on dry matter digestibility

Effects of xylanase supplementation on DM digestibility have been mixed, with some studies showing a favourable response. Addition of xylanase to diets based on wheat or its by-products improved apparent ileal and total-tract DM digestibility 4 and 1%, respectively, in grower pigs (Yin et al. 2000b). In weanling pigs, xylanase supplementation in combination with β-glucanase of diets containing hull-less barley improved both apparent ileal and total tract digestibility of DM 15 and 6%, respectively, (Baidoo et al. 1998) and of diets based on barley and pollard improved the apparent ileal digestibility of DM 5%, without affecting total tract digestibility (Graham et al. 1988). In addition, the same enzyme combination improved the total tract digestibility of DM in grower-finisher pigs fed diets containing normal or high fat oat (Thacker and Rossnagel 2005).

Xylanase supplementation did not affect DM digestibility in weanling pigs fed meal and pellet form rye-based diets (Thacker et al. 1991). Furthermore, addition of xylanase to wheat-based diets did not improve either ileal or total tract dry (organic) matter digestibility in weaner pigs (Diebold et al. 2005) or total tract digestibility of DM in nursery and finishing pigs (Mavromichalis et al 2000). Xylanase, in combination with β-glucanase, in diets containing a variety of cereals, reduced dry (organic) matter digestibility 50% in the stomach of weaned piglets, without affecting the digestibility of organic matter at the other sites of the digestive tract (Högberg and Lindberg 2004). The same enzyme combination did not influence the apparent digestibility of DM in each of the four segments examined of the small intestine of weaned pigs fed wheat- and canola meal-based diets (Zijlstra et al. 2004). Moreover, supplementary xylanase together with β-glucanase did not influence total tract digestibility of DM in growing or finishing pigs fed diets based on barley or rye, respectively (Thacker et al. 1992a). Finally, supplementing hull-less barley based diets with xylanase did not affect apparent ileal or total tract digestibility of DM in young pigs (Yin et al. 2001). Combined, the data indicate that effects of xylanase on dry matter digestibility are dose dependent and may depend on the amount of arabinoxylans in the diet and whether the arabinoxylans are indeed a factor limiting dry matter digestibility in the specific diet.

Dry matter digestibility is generally not considered in least-cost diet formulation, but may have an importance in situations with a need to reduce dry matter excretion. Fresh or dry faeces output as a percentage of DM intake, or DM concentration in faeces of grower pigs fed diets

based on wheat or wheat by-products supplemented with xylanase did not differ (Yin et al. 2000b).

1.6.5.4 Effect on performance

The consequences of xylanase supplementation on pig performance have been studied. Supplemental xylanase in corn- and wheat-based diets improved ADG 9.2%, ADFI 4%, and feed efficiency 5.3% in grower pigs (Van Lunen and Schulze 1996). With different rates of xylanase supplementation, ADG and feed efficiency were improved linearly and quadratically in grower pigs fed wheat-based diets, achieving the highest responses with diets supplemented with 11,000 U g^{-1} xylanase (Barrera et al. 2004). In another experiment, different rates of xylanase supplementation in combination with β-glucanase increased ADFI, ADG and body weight quadratically in weaned pigs fed diets based on wheat and canola meal, achieving the best performance with the diet supplemented with 2 g kg^{-1} carbohydrase, resulting in 16, 13 and 7% higher ADFI, ADG and body weight, respectively, compared to the control diet (Zijlstra et al. 2004). However, enzyme supplementation reduced feed efficiency of pigs linearly. In addition, the same combination of supplementary enzymes improved ADG 5%, without affecting ADFI or feed efficiency, of growing pigs fed diets containing barley, wheat, SBM, and canola meal (Bell and Keith 1989).

In contrast, supplementing xylanase to rye-based diets in meal and pellet forms did not affect the ADG or ADFI in weanling pigs, but enzyme addition to the diet in meal form improved feed efficiency 10% (Thacker et al. 1991). Furthermore, xylanase supplementation did not improve performance of weanling pigs fed rye-based diets (Bedford et al. 1992). Similarly, xylanase supplementation did not improve performance of weaning pigs fed wheat- or barley-SBM diets (Inborr et al. 1993). Xylanase supplementation did not improve performance in nursery or finisher pigs fed wheat-based diets (Mavromichalis et al 2000). Supplementary xylanase in combination with β-glucanase did not influence the performance of growing or finishing pigs fed diets based on barley or rye, respectively (Thacker et al. 1992a), or of grower-finisher pigs fed diets containing normal or high fat oat (Thacker and Rossnagel 2005). Moreover, the same enzyme combination did not affect the feed intake or ADG of weaned piglets fed diets composed of main cereals grains and wheat bran (Högberg and Lindberg 2004). Combined, the data indicate that effects of xylanase on growth performance are dose dependent and may depend of the amount of arabinoxylans in the diet and whether the arabinoxylans are indeed a factor limiting performance of pig fed the specific diet.

1.7 Summary

The value and use of distiller's feeds in swine rations are not fully realized due to the inconsistency of available information on its nutritional value for swine. Product variability is seemed to be a primary concern with the use of DDGS in swine rations. In addition, previous studies with corn DDGS revealed a reduced AA digestibility (Wahlstrom et al. 1970) and an inappropriate AA profile for pigs (Cromwell et al. 1983). The use of corn DDGS in swine rations has been tested with different inclusion rates in pigs of different growth stages. Information on the use of wheat DDGS in swine nutrition remains entirely lacking.

The relatively high fibre content in DDGS may have limited its use as an energy source in swine ration formulation. However, the DE dilution effect of high fibre content can be overcome

with the counteracting effect of high fat content of DDGS, achieving a higher DE value compared to that of the original cereal grain (Newland and Mahan 1990). A great variability in DE and ME content of corn DDGS exists with samples from different sources (Spiehs et al. 2002) and different inclusion rates of the same sample (Spiehs et al. 2000). Different sources and inclusion rates of DDGS affect the energy digestibility differently causing variability in DE and ME contents.

The protein quality of DDGS is low due to deficiency of several indispensable AA (Newland and Mahan 1990). Particularly, the lack of lysine, the first limiting AA in swine nutrition, is critical. Some of the lysine is destroyed or made unavailable during the fermentation and/or drying processes of DDGS. A considerable variation in crude protein and AA composition exists in corn DDGS samples originated from various sources (Cromwell et al. 1993; Spiehs et al. 2002) and AA digestibility of DDGS in swine is lower than predominant cereal ingredients (Wahlstrom et al. 1970).

Despite the higher nutrient composition compared to the original cereal grain, the concentrated NSP fraction of DDGS may hamper the action of digestive enzymes in the small intestine and affect the digestion process of nutrients (van Barneveld et al. 1995, Grieshop et al. 2001). However, the hydrolysis of phytate-P during fermentation increased the availability of P in DDGS (Singsen et al. 1972 as referenced by Cromwell 1979).

Some studies reported a numerical reduction in VFI when corn DDGS is included in swine diets (Wahlstrom and Libal 1980; Whitney and Shurson 2004). Reasons for the reduction in VFI are still unclear but high fibre content, the AA profile that is not appropriate for pigs and high energy density can be considered as possible factors associated with reduced feed intake.

With the introduction of exogenous enzymes to alleviate the detrimental effects associated with NSP in feed ingredients, xylanase is widely used in commercial livestock rations to maximize the nutrient utilization from feedstuffs. Based on concentrated NSP components in wheat DDGS, use of supplementary xylanase would be worthwhile; however, the results of the studies conducted to evaluate the effect of xylanase supplementation of wheat-based diets on nutrient digestibility and growth performance of pigs are controversial. Plausible factors contributing to the inconsistency in nutrient digestibility among studies might be the variations in substrate level of ingredients used, the level of supplementary xylanase added and the variations in genetic potential and age of experimental animals.

Based on the gathered information or lack thereof, the following research objectives were developed:

To determine the energy, AA and P digestibility of wheat and corn DDGS.
To evaluate the effect of DDGS on DM, N and P excretion patterns.
To determine whether feeding diets containing wheat or corn DDGS result in equal growth performance of grower-finisher pigs fed a wheat control diet.

Appendix 2a. Nutritional value of wheat and corn distiller's dried grain with solubles: digestibility and digestible contents of energy, amino acids and phosphorus, nutrient excretion and growth performance of grower-finisher pigs

Abstract

Two experiments were conducted to evaluate the nutritional value of distiller's dried grains with solubles (DDGS) samples derived from corn, wheat and a wheat/corn blend (4:1). Specifically, the digestibility and digestible contents of energy, amino acids (AA) and P, N and P excretion, and growth performance were determined in grower-finisher pigs. In Experiment (Exp.) 1, 12 ileal cannulated barrows (64.6 ± 6.4 kg) had restricted access (2.6 x maintenance) to a wheat-control diet or one of three diets containing 40% DDGS sample of corn, wheat or wheat/corn origin that replaced wheat. For energy, apparent total tract digestibility was highest for wheat (85%; $P < 0.05$) and did not differ among the DDGS samples (77 to 79%; $P > 0.10$). Total tract digestible energy (DE) was highest for corn DDGS (4292 kcal kg^{-1} DM; $P < 0.05$) than wheat/corn DDGS, wheat DDGS and wheat samples (4038, 4019 and 3807). For lysine, apparent ileal digestibility (AID) was highest for wheat (71%; $P < 0.05$) and did not differ among DDGS samples (59 to 63%; $P > 0.10$). The AID lysine content was highest for corn DDGS (0.51% DM; $P < 0.05$), intermediate for wheat/corn DDGS and wheat DDGS (0.45 and 0.42), and lowest for wheat (0.37%). For P, total tract digestibility was lowest for wheat (15%; $P < 0.05$) and did not differ among DDGS samples (53 to 56%; $P > 0.10$). Total N excretion was highest for wheat/corn DDGS and wheat DDGS (55 and 58 g d^{-1}; $P < 0.05$), intermediate for corn DDGS (44) and lowest for wheat (36). Total P excretion did not differ among DDGS (11 g d^{-1}) and was lowest for wheat (8; $P < 0.05$). In Exp. 2, 100 pigs (52.0 ± 3.3 kg) were fed a wheat-pea control diet or one of three diets containing 25% of the three DDGS samples (3.375 Mcal DE kg^{-1}; 2.50 g SID lysine $Mcal^{-1}$ DE) for 5 wk. Overall, average daily feed intake (ADFI) and daily gain (ADG) were higher for pig fed the wheat control diet than the DDGS-containing diets ($P < 0.05$) but feed efficiency did not differ ($P > 0.10$). In summary, the digestible nutrient content of wheat DDGS is lower than corn DDGS and higher than wheat. Following pre-characterization of digestible nutrient profile, feeding DDGS reduced growth performance indicating that further research is required to improve the nutritional value of DDGS.

Introduction

Distiller's dried grains with solubles (DDGS) is a by-product from the cereal grain-based ethanol and alcohol beverage industries (Newland and Mahan 1990). With the rapid growth of the ethanol industry, increasing quantities of DDGS are available for livestock rations, including DDGS produced in western Canada from wheat or corn. In general, DDGS has higher concentrations of nutrients such as protein, fat, vitamins, minerals, and fibre than its parent grain. These nutrients are concentrated due to the removal of most of the cereal starch as ethanol and carbon dioxide during the fermentation process (Weigel et al. 1997).

Product variability and lack of information about the nutritional value of DDGS from different sources were primary reasons for the initial reluctance of using corn DDGS in swine

diets. In addition, reduced AA digestibility (Wahlstrom et al. 1970), and an AA profile that is not well suited for pigs (Cromwell et al. 1983) were concerns. Due to the construction of new ethanol plants with modern fermentation and drying technologies in the upper Midwest, the nutritional value of corn DDGS for swine was re-addressed indicating that high quality corn DDGS that is presumed to be less variable in terms of nutrient content has become available for the livestock industry (Shurson et al. 2000; Spiehs et al. 2002; Whitney and Shurson 2004); however, the digestible nutrient content of corn DDGS remains to be verified. In contrast, the nutritional value of wheat DDGS for swine has never been described; therefore, its potential for the swine industry is not documented. The continuously increasing supply of corn DDGS and wheat DDGS suggests that evaluation of their nutritional value for swine is worthwhile to support development of cost-effective feeding programs. For any feed ingredient for swine, an understanding of the digestible nutrient content is critical to achieve accurate diet formulation. In addition, nutrient excretion is a major concern for the swine industry due to its potential impact on the environment, and the effects of DDGS on nitrogen (N) and phosphorus (P) excretion patterns should be evaluated. The effects of DDGS on swine growth performance should also be described, because the high fibre content in DDGS may reduce nutrient digestibility and voluntary feed intake, and thereby growth performance.

The objectives of the present study were to determine the energy, AA and P digestibility and digestible nutrient content of DDGS produced from wheat and corn, to evaluate the effect of DDGS on N and P excretion patterns, and to determine whether feeding diets containing DDGS results in growth performance equal to grower-finisher pigs fed a wheat-based control diet.

Materials and Methods

Ingredients

Three DDGS samples were obtained from two sources: corn DDGS from an unknown U.S.-origin via a commercial feed mill (Federated Co-op, Saskatoon, SK), and wheat DDGS and wheat/corn DDGS from an ethanol plant (Mohawk Canada, Minnedosa, MB) that used Hard Red Spring wheat as a feedstock. Occasionally, wheat and corn are fermented together to overcome periods of limited wheat supply, and the feedstocks wheat and corn were blended and fermented in a 4:1 ratio for production of the specific wheat/corn DDGS used in this experiment. The same three batches of DDGS were used in the digestibility and performance studies.

Experimental Protocol

The animal protocols were approved by the University of Saskatchewan Committee of Animal Care and Supply and followed principles established by the Canadian Council on Animal Care (1993). Two experiments (Exp.) were conducted at Prairie Swine Centre Inc. (Saskatoon, SK).

Exp. 1 - Digestibility Study. Four diets were tested in two experimental periods using cannulated grower-finisher pigs: one wheat control diet and three diets with DDGS. The sole source of energy and AA in the control diet was wheat whereas in the other three experimental diets, three different types of DDGS (corn, wheat/corn, or wheat) were mixed with wheat (Table 1). Chromic oxide was included as an indigestible marker and diets were fortified to meet or exceed vitamins and mineral requirements [National Research Council (NRC) 1998]. A total of 12 barrows (64.6 ± 6.4 kg; PIC Canada Ltd., Airdrie, AB) were surgically fitted with an T-

cannula at the distal ileum and fed two experimental diets each in a controlled change-over design (Li et al. 1994), for a total of 24 observations or six observations per diet.

Each 11-d experimental period consisted of a 6-d acclimation to experimental diets followed by a 3-d collection of faeces and urine and then a 2-d collection of ileal digesta. The 12 pigs were housed in individual metabolism pens in one room. The dimensions of the pens were 1.5 (length) x 1.5 (width) x 0.9 m (height), and allowed freedom of movement of pigs during the entire experiment. The flooring of the pen was plastic-coated expanded metal and the siding was sturdy PVC-planking with a transparent plastic window to allow visual contact between pigs in adjacent pens. A single-space feeder and a bowl-drinker were located at the front of each pen. The room was maintained within the thermo-neutral zone of the pigs, with a 14 hr light (0700 to 2100)/10 hr dark cycle. During the entire experiment, diets were provided in wet-mash form, in a 1:1 water to mash ratio. To avoid orts, daily feed allowance was adjusted to 2.6 x maintenance [2.6 x 110 kcal DE kg^{-1} body weight $(BW)^{0.75}$; NRC 1998] based on average BW at the start of each 11-d experimental period using an estimated diet DE content of 3,300 kcal kg^{-1}. Diets were fed in two equal meals at 0800 and 1600; 1.95 and 2.20 kg feed d^{-1} during the first and second period, respectively. Pigs had free access to water throughout the experiment.

During the collections, representative diet samples were collected. Faeces were collected for 3 d twice per day (0800 and 1600) using faeces collection systems (Van Kleef et al. 1994). Urine was quantitatively collected for 3 d during faeces collections for a minimum of two times per day using urine trays and collection bottles. Twenty mL of 12N HCl was added to the collection bottles prior to each collection to prevent volatilization of urinary N. Of the collected urine, 10% was sub-sampled. Digesta samples were collected in 4% formic acid every 2 h for 10 h d^{-1} during 2 d, using plastic bags affixed to the open T-cannula barrel. Collected faeces, urine and digesta samples were pooled per pig over each collection period and stored with diet samples in a freezer maintained at –20 °C.

Exp. 2 - Performance Study. Four diets (one wheat-based control diet and three DDGS-containing diets) were formulated and used in a performance study with grower-finisher pigs (52.0 ± 3.3 kg; PIC Canada Ltd., Airdrie, AB). The main ingredients of the control diet were wheat, peas, and soybean meal. In the other three experimental diets 25% DDGS was included, replacing a portion of wheat, soybean meal and dicalcium phosphate. Diets were formulated, using the digestible energy, AA, and P content determined for each DDGS sample in the digestibility study, to meet or exceed the requirements for AA and other nutrients (NRC 1998), to 3.375 Mcal DE kg^{-1} and 2.50 g standardized ileal digestible lysine $Mcal^{-1}$ DE (Table 2). Other essential AA were formulated as a ratio to lysine (NRC 1998). A total of 100 grower pigs (40 barrows and 60 gilts ensuring identical gender within each group of four pens) were selected based on BW and average daily gain (ADG) since birth, randomized within gender, and housed in one room, with five pigs per pen, in 20 pens. Barrows and gilts were penned separately and each of the four experimental diets was fed to two pens with barrows and three pens with gilts, for a total of 5 observations per diet. Two pigs from separate pens fed different diets were removed from the experiment due to tail biting and data collected from these pigs were excluded from statistical analyses.

The duration of the study period was 6 wk: a 1-wk adaptation to the room, pen, and pen mates followed by 5-wk feeding of experimental diets. The switch from grower diet to experimental diets was abrupt, i.e., without having a period of mixing the diets together. Pens measured 2.36 x 1.68 m. The flooring of the pen was fully-slatted concrete and the siding was sturdy PVC-planking. A single-space feeder was located at the front and a nipple-drinker was

located at the back of the pen. The room was maintained within the thermo-neutral zone of the pigs, with a 14 hr light (0700 to 2100)/10 hr dark cycle. Diets were provided as a dry mash and diets and water were supplied *ad libitum* throughout the experiment.

Pigs were weighed at the initiation of feeding the experimental diets (d 0), and weekly thereafter, (d 7, 14, 21, 28, and 35). Feed disappearance was measured on each weigh day. The data were used to calculate ADG, ADFI, and feed efficiency (G:F).

Chemical Analyses

Faeces and digesta samples were thawed, homogenized, sub-sampled and freeze-dried. Urine was thawed, homogenized, sub-sampled and frozen. Ingredient, feed and freeze-dried faeces and digesta samples were ground through a 1-mm screen.

Chemical analyses were conducted in duplicate. For the digestibility study, the ingredient, feed, faeces and digesta samples were analysed for dry matter (DM) content by drying at 135 °C in an airflow type oven for 2 h (method 930.15; AOAC 1990). Feed, faeces and digesta samples were analysed for chromic oxide after ashing at 450 °C (Fenton and Fenton 1979) and gross energy using an IKA oxygen bomb calorimeter (model C 5003, IKA GmbH & Co. KG, Staufen, Germany). The calorimeter was operated in dynamic mode and benzoic acid was used as a caloric standard for calibration. Ingredient, feed and faeces samples were analysed for P according to the method described by Zasoski and Burau (1977) and urine was analysed for P using the molybdo-phosphate method (method 964.06; AOAC 1990). Feed, faeces and urine were analyzed for N by combustion (method 968.06; AOAC 1990) using a Leco protein/N analyzer (model FP-528, Leco Co., St. Joseph, MI). Ingredient, feed and digesta samples were analysed for AA (method 982.30E; AOAC 1990) at the University of Missouri, Columbia, MO. In addition, the wheat sample used in the digestibility study and the DDGS samples were analyzed for crude protein (CP; method 988.05; AOAC 1990), crude fat (method 954.02; AOAC 1990), ash (method 942.05; AOAC 1990), crude fibre (method 962.09; AOAC 1990), acid detergent fibre (ADF) and neutral detergent fibre (NDF) using an Ankom fiber analyzer (model ANKOM^{200}, Ankom Technology, Fairport, NY) using sodium sulphite and α-amylase in the NDF procedure, and non-protein N (NPN; Licitra et al. 1996). The DDGS samples were analyzed for intact phytate, i.e., inositol hexaphosphate (IP6), and lower IP (IP2 to IP5) by high performance liquid chromatography (Newkirk and Classen 1998) and soluble and insoluble non-starch polysaccharides (NSP) and constituent sugars by gas-liquid chromatography (Englyst and Hudson 1987).

Calculations and Statistical Analyses

Apparent ileal and total tract digestibility of nutrients and nutrient excretion were calculated for the four diets using the indicator method (Adeola 2001). Coefficients for the wheat ingredient were assumed equal to wheat control diet for energy and AA, whereas the digestibility coefficients for P were corrected for the digestible P provided by dicalcium phosphate. The digestibility coefficients and digestible nutrient content of the three DDGS samples were separated from wheat using the difference method (Fan and Sauer 1995). Standardized ileal digestibility (SID) of AA was calculated from apparent ileal digestibility (AID) coefficients using the method of Yin et al. (2002), based on the mean endogenous AA composition of basal endogenous protein (Jansman et al. 2002). The digestible nutrient content was calculated using total nutrient content multiplied by the digestibility coefficients.

Pig was considered the experimental unit for the digestibility study and pen for the performance study. Digestibility variables were analysed using the general linear models procedure of SAS (SAS Institute, Inc. 1996). Means were reported as least-square means [± pooled standard error of the mean (SEM)] and were separated using the probability of difference; $P < 0.05$ was considered significant to test the hypotheses. If pertinent, trends ($0.05 < P < 0.10$) were reported and $P > 0.10$ was considered non-significant. Performance variables were analyzed by analysis of variance using the MIXED procedure of SAS (Wang and Goonewardene 2004) using a statistical model with the following factors: diet, gender and diet x gender, and initial BW as a covariate. The wheat was compared to the three DDGS samples combined using a contrast.

Results

Chemical characteristics

Overall for the measured characteristics, the content was lower for the wheat sample than the three DDGS samples, except for phytate. The CP content was highest for wheat DDGS (Table 3). The NPN content of wheat/corn DDGS and wheat DDGS was 6%-units higher than for corn DDGS. The crude fat content was 10%-units higher for corn DDGS than wheat DDGS. The ash, ADF, NDF, and crude fibre contents were similar among the DDGS samples, and were all higher than in wheat.

Similar to CP content, the total and indispensable AA contents were highest for wheat DDGS followed by wheat/corn DDGS and corn DDGS, with the exception of leucine and lysine (Table 3). The leucine and lysine content was highest for corn DDGS. With the exception of lysine, the AA content in wheat DDGS doubled that of wheat.

Among the DDGS samples, wheat DDGS had the highest total P content and corn DDGS had the highest intact phytate (IP6) content (Table 4). Wheat did not contain any of the lower forms of phytate (IP2, IP3, IP4 and IP5). In addition to phytate, wheat DDGS contained all lower inositol phosphate forms of phytate; corn DDGS and wheat/corn DDGS did not contain IP2.

Among the DDGS, wheat DDGS had he highest soluble and total NSP content, but corn DDGS had the highest insoluble NSP content (Table 4). The constituent sugars were similar among the DDGS, with wheat DDGS having the highest soluble xylose, arabinose and glucose content. Concentrations of mannose and galactose were overall low.

Nutrient digestibility and content

The apparent ileal and total-tract digestibility of energy did not differ among DDGS samples ($P > 0.10$; Table 5); however, ileal and total-tract energy digestibility was 8 and 9%, respectively, higher for the wheat than for the DDGS samples ($P < 0.05$). The total-tract digestibility of P did not differ among the DDGS samples ($P > 0.10$), but was 40%-units higher for DDGS than the wheat ($P < 0.05$).

The AID of indispensable and total AA (Table 5) and the SID of the indispensable AA (Table 6) were similar among DDGS samples ($P > 0.10$), with the exception of threonine. The AID of threonine was similar for wheat/corn DDGS and wheat DDGS ($P > 0.10$), but lower for corn DDGS ($P < 0.05$) and the SID of threonine was lower for corn DDGS than for wheat/corn DDGS ($P < 0.05$). However, AID and SID of the indispensable and total AA were higher for

wheat than DDGS ($P < 0.05$), except for the AID of arginine, leucine, methionine, threonine, tryptophan, and valine ($P > 0.10$).

Among DDGS samples, the contents of standardized ileal digestible AA were highest for wheat DDGS followed by wheat/corn DDGS and corn DDGS ($P < 0.05$; Table 7), except for leucine, lysine, methionine, and threonine. Specifically, ileal digestible leucine contents were lowest for wheat DDGS and highest for corn DDGS ($P < 0.05$). The ileal digestible lysine, methionine and threonine contents were similar for wheat DDGS and wheat/corn DDGS ($P > 0.10$); however, corn DDGS had the highest contents for lysine and the lowest contents for methionine and threonine ($P < 0.05$). Overall, ileal digestible contents of indispensable AA were lower for the wheat than DDGS ($P < 0.05$).

The apparent ileal DE content did not differ among DDGS samples ($P > 0.10$; Table 7), but total tract DE content was higher for corn DDGS than wheat/corn DDGS and wheat DDGS ($P < 0.05$). Total tract DE content tended to be higher for wheat/corn DDGS and wheat DDGS than wheat ($P = 0.06$), and ileal and total tract DE contents were lower for wheat than the DDGS samples combined ($P < 0.05$). The digestible P content was similar ($P > 0.10$) among DDGS samples and higher for DDGS than wheat ($P < 0.05$).

Nutrient excretion

The DM intake was similar among pigs fed wheat control and DDGS diets ($P > 0.10$; Table 8). Pigs fed wheat/corn DDGS and wheat DDGS had a higher daily N and P intake than pigs fed corn DDGS ($P < 0.05$). The N and P intake was lower for pigs fed wheat than pigs fed DDGS ($P < 0.05$).

The DM excretion on daily basis and as a percentage of intake was similar among pigs fed DDGS diets ($P > 0.10$; Table 8). The DM excretion was higher for pigs fed DDGS than the wheat control diet ($P < 0.05$).

Pigs fed wheat/corn DDGS excreted the highest amount of faecal N on a daily basis, followed by pigs fed the wheat DDGS and corn DDGS ($P < 0.05$; Table 8). Pigs fed DDGS had a higher faecal N excretion than pigs fed the wheat control ($P < 0.05$). Similarly, feeding DDGS increased urinary N excretion compared to the wheat control ($P < 0.05$). Total N excretion was higher for pigs fed wheat/corn DDGS and wheat DDGS than pigs fed corn DDGS ($P < 0.05$). Total N excretion did not differ between pigs fed the wheat control and corn DDGS ($P > 0.10$). Daily N retention was similar among pigs fed DDGS ($P > 0.10$), but was lower for pigs fed the wheat control than for pigs fed DDGS ($P < 0.05$).

Daily excretion of faecal, urinary and total P and P retention were similar among pigs fed DDGS ($P > 0.10$; Table 8), and was lower for the wheat control than DDGS ($P < 0.05$). Percentage of N and P retained did not differ among the four experimental diets ($P > 0.10$).

Growth performance

For the performance trial, final BW, ADG and ADFI did not differ among pigs fed diets containing DDGS for any of the weeks or the entire experimental period ($P > 0.10$; Table 9). Final BW, ADG and ADFI were higher for pigs fed the wheat control than for pigs fed DDGS ($P < 0.05$). However, DDGS did not affect feed efficiency of pigs ($P > 0.10$).

Discussion

In the present study, the chemical and nutritional properties varied among samples of DDGS, similar to previous studies (e.g., Carpenter 1970; Cromwell and Stahly 1986; Cromwell et al. 1993; Stein et al. 2006). Generally, nutrient variability of DDGS cannot be entirely avoided, because DDGS is a by-product of a process primarily aimed at the production of ethanol. In the present study, the variation was large, because DDGS was produced from two feedstocks (wheat and corn) at two ethanol plants. Overall, factors including the type of cereal grain used for fermentation, method of fermentation (batch or continuous), completeness or duration of the fermentation process, drying temperature and duration, and the amount of dried solubles blended with distiller's dried grains can affect the chemical, physical and nutritional characteristics of DDGS (Carpenter 1970; Olentine 1986; Spiehs et al. 2002). The nutrient composition of DDGS should still reflect the nutrient content of original cereal grain, with a higher concentration of remaining nutrients following starch removal (Sosulski and Tarasoff 1997; Weigel et al. 1997; Mustafa et al. 1999). Indeed, the nutrient content was higher for the wheat DDGS sample than for the wheat sample used in the present study.

One of the main observations of the present study was a lower total content of the first-limiting AA, lysine, in wheat DDGS compared to corn DDGS, despite a markedly higher CP and total AA content in wheat DDGS than corn DDGS. This low total lysine content and the high NPN content indicates that some of the lysine and AA were damaged during the fermentation and/or drying processes of the wheat DDGS and wheat/corn DDGS. These two DDGS samples had a dark colour with slightly burnt odour, suggesting that the DDGS was overheated during the drying process (Cromwell et al. 1993; Fastinger and Mahan 2006). The comparatively low moisture content of wheat-based DDGS also indicated excessive drying. In contrast to wheat DDGS, the corn DDGS was lighter in colour with sweet and slightly fermented odour suggesting a supply of appropriate heat during drying. Following overheating, lysine forms complexes with carbonyl groups, the Maillard reaction, which is associated with a colour change. The Maillard reaction is stimulated by heat in the presence of moisture, the exact conditions present in the drying process and that that should thus be reduced to prevent lysine degradation.

Apparent ileal or total-tract digestibility of energy and AID or SID of indispensable AA were lower for DDGS compared to the wheat sample. Soluble and insoluble NSP were concentrated with other nutrients in DDGS during fermentation (Mustafa et al. 1999) and likely contributed to the lower digestibility of DM, energy and AA in DDGS in the present study (Zijlstra et al., 1999; de Lange 2000; Jondreville et al. 2001). The measured digestibilities for AA in the present study compared to the range of coefficients measured recently for corn DDGS (Fastinger et al. 2006; Stein et al. 2006) and wheat DDGS (Nyachoti et al. 2005). Based on fibre content of DDGS, plausible factors contributing to low apparent AA digestibility in DDGS could be decreased enzymatic breakdown of dietary protein, thereby reduced absorption and increased undigested protein (AA) in digesta, or increased endogenous AA losses (Jondreville et al. 2001).

Undigested P is excreted in faeces, and may impact the environment negatively (Cromwell et al. 1993; NRC 1998). Interestingly, P digestibility in DDGS was higher compared to wheat in the present study. Approximately 60 to 70% of the total P in a cereal-based diet is bound to phytate, and this phytate-P is not digested by swine (Baker 1991). The high P digestibility in DDGS was consistent with previous research [Singsen et al (1972) as referenced by Cromwell (1979)] indicating that P availability is enhanced in DDGS due to phytate-P hydrolysis. In the present study, the breakdown of phytate during fermentation was validated by the presence of less

complex forms of phytate and the reduced intact phytate (IP6) content in wheat DDGS compared to the wheat sample. A higher P digestibility in DDGS compared to cereals suggests that feeding DDGS might improve P management in swine diets and manure, in contrast to N.

Digestible nutrient content information is important for diet formulation. Despite the highest energy digestibility, apparent ileal and total-tract DE content remained lower in the wheat sample than in the wheat DDGS, contrasting previous research indicating that wheat had a higher DE content than wheat DDGS (Nyachoti et al. 2005). The higher fat content in corn DDGS compared to wheat DDGS, is associated with a higher gross energy content and therefore a higher DE content in corn DDGS than wheat DDGS (Spiehs et al. 2002). The achieved DE content in DDGS indicates that the DE reduction caused by a high NSP content can be overcome with a high fat content. The substantially higher digestible P content in DDGS is due to a higher P content and digestibility. Even though the ileal digestibility values of most of the indispensable AA were higher in the wheat sample than DDGS, the digestible AA contents in DDGS was higher due to higher AA content in DDGS samples.

In the present study, DM excretion was higher for pigs fed DDGS-containing diets than for pigs fed the wheat-control diet, suggesting that feeding DDGS will increase manure volume. The increased DM excretion might be due to the high NSP content of DDGS, because addition of a fibre source to the diet elevates faecal DM excretion in pigs (Cherbut et al. 1988), especially fermentable NSP (Canh et al. 1998).

The higher N intake of pigs fed DDGS-containing diets compared to wheat-control diets was due to a higher CP content in DDGS, and was directly related to an increased N excretion in faeces and urine, especially with wheat DDGS. Almost 25% of the CP was NPN in wheat DDGS, and is partially responsible for the increased N excretion. The increased urinary N excretion indicates increased AA catabolism, suggesting an imbalanced AA profile or a limitation in one or more limiting AA in DDGS (de Lange, 2004). Interestingly, N retention as a percentage of N intake was not affected by DDGS in the diet, indicating that CP and AA contained in DDGS can be utilized by the pig.

Intake, excretion and retention of P were affected by DDGS. The higher P content in DDGS compared to wheat increased P intake of pigs fed diets with DDGS, especially for wheat/corn DDGS and wheat DDGS. As a consequence of increased P intake with DDGS, increased amounts of P appeared in faeces and urine (Cromwell et al. 1993; Ekpe et al. 2002). The increased P digestibility in DDGS could not entirely overcome the increased content of digestible P in DDGS. The amount of digested P surpassed the P requirement of pigs fed DDGS in the present study, resulting in excess urinary P excretion (Ekpe et al. 2002). Despite the increased excretion, daily P retention was higher for pigs fed DDGS-containing diets than pigs fed the wheat control diet. Similar to N retention, P retention as a percentage of P intake was not affected by dietary DDGS, indicating once more that P in DDGS was utilized to a large extent by pigs in the present study, and contributed directly to meeting the digestible P requirement (Jongbloed et al. 1999).

In the present study, inclusion of DDGS reduced growth performance of pigs without affecting feed efficiency. The DDGS contains a higher digestible energy and AA content than wheat, but following pre-characterization and incorporation of the digestible nutrient content information in diet formulation, DDGS caused a reduction in voluntary feed intake, ADG and final BW. Reasons for the reduced feed intake remain unclear; dietary inclusion of DDGS might negatively affect palatability (Whitney and Shurson 2004), or the high NSP content in DDGS

might play a role, because a high dietary fibre content reduces feed intake in pigs (Noblet and Le-Goff 2001).

The increased fermentation and increased CP content in the diet limiting in lysine is likely caused extra heat increment as a result of catabolism of excess AA (Henry et al. 1992). Indeed, feeding DDGS to swine increased N excretion, and thereby increased the requirement of energy for N excretion, leaving less energy available to support growth (Spiehs et al. 2002). In addition, the daily intake of digestible lysine was lower for pigs fed diets with DDGS than fed the wheat control diet, mainly due to a lower feed intake, because the diets were formulated to an equal digestible lysine content. The reduced digestible lysine intake for DDGS, together with reduced lysine availability in DDGS may have constrained protein accretion of pigs fed diets with DDGS, because lysine intake below requirement will suppress growth performance of grower-finisher pigs (Friesen et al. 1994).

The results of the present study indicate that wheat DDGS is a by-product with a nutritional value for swine that is higher than wheat. Wheat DDGS has a lower nutritional value than corn DDGS, and the AA damaged by processing, a higher xylose content and lower crude fat content might together be constraints to the nutritional value of wheat DDGS for pigs. Dietary DDGS might increase N and P excretion in pigs. Finally, the nutritional value of wheat DDGS can be enhanced by improving its digestible AA content with improved fermentation and drying processes and reducing the impact of NSP with supplementary enzymes or other technologies.

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Table 1. Ingredient composition of experimental diets used in the digestibility study

Ingredient (%)	Wheat control	Distiller's dried grains with solubles		
		Corn	Wheat/corn[z]	Wheat
Wheat	96.3	56.3	56.3	56.3
Distiller's dried grain with solubles				
Corn	-	40.0	-	-
Wheat/corn	-	-	40.0	-
Wheat	-	-	-	40.0
Limestone	1.1	1.1	1.1	1.1
Dicalcium phosphate	0.8	0.8	0.8	0.8
Mineral mix[y]	0.5	0.5	0.5	0.5
Vitamin mix[x]	0.5	0.5	0.5	0.5
Chromic oxide	0.4	0.4	0.4	0.4
Salt	0.4	0.4	0.4	0.4

[z]Derived from the combined fermentation of wheat and corn in a 4:1 ratio.

[y]Provided per kg of diet: Zn, 100 mg as zinc sulfate; Fe, 80 mg as ferrous sulfate; Cu, 50 mg as copper sulfate; Mn, 25 mg as manganous sulfate; I, 0.5 mg as calcium iodate; Se, 100 μg as sodium selenite.

[x]Provided per kg of diet: vitamin A, 8,250 IU; vitamin D_3, 825 IU; vitamin E, 40 IU; niacin, 35 mg; D-pantothenic acid, 15 mg; riboflavin, 5 mg; menadione, 4 mg; folic acid, 2 mg; thiamine, 1 mg; D-biotin, 200 μg; vitamin B_{12}, 25 μg.

Table 2. Ingredient composition and calculated energy and lysine content of experimental diets used in the performance study

Ingredient (%)	Wheat control	Distiller's dried grains with solubles		
		Corn	Wheat/corn[z]	Wheat
Wheat	63.14	41.64	41.18	41.17
Peas	25.00	25.00	25.00	25.00
Distiller's dried grains with solubles				
Corn	-	25.00	-	-
Wheat/corn	-	-	25.00	-
Wheat	-	-	-	25.00
Soybean meal	7.20	4.40	4.40	4.40
Dicalcium phosphate	1.10	0.40	0.40	0.40
Canola oil	0.90	0.70	1.20	1.20
Limestone	0.75	1.00	1.00	1.00
Mineral mix[y]	0.50	0.50	0.50	0.50
Vitamin mix[x]	0.50	0.50	0.50	0.50
Sodium bicarbonate	0.29	0.29	0.29	0.29
L-Lysine-HCl	0.27	0.32	0.33	0.34
Salt	0.20	0.20	0.20	0.20
L-Threonine	0.10	0.05	-	-
DL-Methionine	0.05	-	-	-
Calculated nutrient content (as fed)				
Digestible energy (Mcal kg^{-1})	3.375	3.375	3.375	3.375
SID Lysine (g $Mcal^{-1}$ DE)[w]	2.50	2.50	2.50	2.50

[z]Derived from the combined fermentation of wheat and corn in a 4:1 ratio.

[y]Provided per kg of diet: Zn, 100 mg as zinc sulfate; Fe, 80 mg as ferrous sulfate; Cu, 50 mg as copper sulfate; Mn, 25 mg as manganous sulfate; I, 0.5 mg as calcium iodate; Se, 100 μg as sodium selenite.

[x]Provided per kg of diet: vitamin A, 8,250 IU; vitamin D_3, 825 IU; vitamin E, 40 IU; niacin, 35 mg; D-pantothenic acid, 15 mg; riboflavin, 5 mg; menadione, 4 mg; folic acid, 2 mg; thiamine, 1 mg; D-biotin, 200 μg; vitamin B_{12}, 25 μg.

[w]Other essential AA were formulated as a ratio to lysine (NRC 1998)

Table 3. Chemical characteristics of wheat, and corn, wheat/corn, and wheat distiller's dried grains with solubles (% DM)

Variable	Wheat	Distiller's dried grains with solubles		
		Corn	Wheat/corn[z]	Wheat
Moisture	11.8	11.8	8.0	8.1
Crude protein	19.8	30.3	42.4	44.5
Non-protein nitrogen	4.6	5.4	12.4	10.2
Crude fat	1.8	12.8	4.7	2.9
Ash	2.1	4.8	5.0	5.3
Acid detergent fibre	2.7	14.6	19.5	21.1
Neutral detergent fibre	9.4	31.2	30.6	30.3
Crude fibre	2.4	7.0	7.8	7.6
Amino acid				
Arginine	0.91	1.33	1.64	1.77
Cysteine	0.48	0.70	0.89	0.96
Histidine	0.46	0.82	0.95	0.99
Isoleucine	0.68	1.14	1.50	1.59
Leucine	1.31	3.52	3.13	3.01
Lysine	0.52	0.83	0.72	0.72
Methionine	0.32	0.61	0.67	0.69
Phenylalanine	0.96	1.51	1.98	2.16
Threonine	0.54	1.09	1.22	1.28
Tryptophan	0.23	0.23	0.37	0.44
Valine	0.84	1.53	1.83	1.91
Total	19.48	28.32	37.25	40.21

Table 4. Phosphorus, inositol phosphates and non-starch polysaccharide (NSP) including constituent sugar profile of wheat, and corn, wheat/corn, and wheat distiller's dried grains with solubles (% DM)

Variable	Wheat	Distiller's dried grains with solubles		
		Corn	Wheat/corn[z]	Wheat
Phosphorus	0.40	0.86	1.02	1.10
Inositol phosphates				
Inositol diphosphate (IP2)	0.00	0.00	0.00	0.08
Inositol triphosphate (IP3)	0.00	0.09	0.09	0.09
Inositol quadraphosphate (IP4)	0.00	0.19	0.18	0.28
Inositol pentaphosphate (IP5)	0.00	0.45	0.33	0.64
Phytate (IP6)	1.39	0.92	0.62	0.81
Total NSP				
Soluble	2.15	1.39	5.35	7.76
Insoluble	7.57	17.85	16.56	15.13
Total	9.72	19.24	21.91	22.89
Xylose				
Soluble	1.03	0.29	2.53	3.08
Insoluble	2.39	5.86	5.58	5.00
Total	3.42	6.15	8.11	8.08
Arabinose				
Soluble	0.68	0.21	1.22	1.58
Insoluble	1.64	4.06	3.51	3.29
Total	2.32	4.27	4.73	4.87
Mannose				
Soluble	0.04	0.29	0.43	0.34
Insoluble	0.10	0.66	0.59	0.58
Total	0.14	0.95	1.02	0.92
Galactose				
Soluble	0.23	0.07	0.27	0.51
Insoluble	0.40	1.37	1.04	0.82

Total	0.63	1.44	1.31	1.33
Glucose				
Soluble	0.07	0.46	0.73	1.09
Insoluble	3.03	5.79	5.78	5.38
Total	3.10	6.25	6.51	6.47

[z]Derived from the combined fermentation of wheat and corn in a 4:1 ratio.

Table 5. Apparent ileal digestibility (%) of energy and amino acids and total tract digestibility (%) of energy and P in wheat, and corn, wheat/corn, and wheat distiller's dried grains with solubles measured in grower-finisher pigs

Variable[z]	Wheat	Distiller's dried grains with solubles			Pooled SEM
		Corn	Wheat/corn[y]	Wheat	
Ileal digestibility (%)					
Energy[x]	71.8	67.3	66.5	65.6	1.63
Amino acid					
Arginine	87.9	85.7	85.2	85.8	1.01
Cysteine[x]	84.1*a*	77.4*b*	78.2*b*	77.0*b*	1.22
Histidine[x]	87.6*a*	81.5*b*	80.8*b*	80.9*b*	1.08
Isoleucine[x]	83.5*a*	78.0*b*	79.4*b*	79.0*b*	1.07
Leucine	85.2	84.4	83.8	82.9	0.72
Lysine[x]	70.6*a*	61.8*b*	62.8*b*	58.6*b*	2.07
Methionine	85.0	84.2	84.2	82.6	0.91
Phenylalanine[x]	87.9*a*	84.0*b*	86.2*ab*	86.4*ab*	0.77
Threonine	73.7*a*	69.4*b*	74.4*a*	72.8*a*	1.04
Tryptophan	85.1	81.7	81.4	82.5	1.79
Valine	86.0	83.0	84.9	84.6	0.81
Total[x]	85.5*a*	79.9*b*	81.5*b*	81.2*b*	0.92
Total tract digestibility (%)					
Energy[x]	84.8*a*	78.7*b*	76.8*b*	77.4*b*	1.39
Phosphorus[x]	14.8*b*	55.5*a*	54.7*a*	53.0*a*	4.15

[z]Means are least-square means for the four feedstuffs.

[y]Derived from the combined fermentation of wheat and corn in a 4:1 ratio.

[x]Wheat differs from the three DDGS ($P < 0.05$).

a-b Within a row, means without a common letter differ ($P < 0.05$).

Table 6. Standardized ileal digestibility (%) of amino acids in wheat, and corn, wheat/corn, and wheat distiller's dried grains with solubles measured in grower-finisher pigs

		Distiller's dried grains with solubles			Pooled
Amino acid[z]	Wheat	Corn	Wheat/corn[y]	Wheat	SEM
Arginine[x]	92.2*a*	88.6*b*	87.6*b*	88.0*b*	1.01
Cysteine[x]	88.4*a*	80.4*b*	80.6*b*	79.2*b*	1.22
Histidine[x]	91.7*a*	83.8*b*	82.8*b*	82.8*b*	1.07
Isoleucine[x]	89.1*a*	81.3*b*	81.9*b*	81.4*b*	1.06
Leucine[x]	88.9*a*	85.8*b*	85.3*b*	84.5*b*	0.71
Lysine[x]	78.3*a*	66.6*b*	68.4*b*	64.1*b*	2.08
Methionine[x]	88.4*a*	86.0*ab*	85.9*ab*	84.2*b*	0.91
Phenylalanine[x]	91.4*a*	86.2*b*	88.0*b*	88.0*b*	0.77
Threonine[x]	85.0*a*	75.0*c*	79.4*b*	77.5*bc*	1.04
Tryptophan[x]	91.2	87.8	85.2	85.7	1.79
Valine[x]	92.4*a*	86.5*b*	87.8*b*	87.4*b*	0.81

[z]Means are least-square means for the four feedstuffs.

[y]Derived from the combined fermentation of wheat and corn in a 4:1 ratio.

[x]Wheat differs from the three DDGS ($P < 0.05$).

a-c Within a row, means without a common letter differ ($P < 0.05$).

Table 7. Standardized ileal digestible amino acid content (% DM), ileal and total tract digestible energy (kcal kg^{-1} DM) and total tract digestible P (% DM) contents in wheat, and corn, wheat/corn, and wheat distiller's dried grains with solubles measured in grower-finisher pigs

Variable[z]	Wheat	Distiller's dried grains with solubles			Pooled SEM
		Corn	Wheat/corn[y]	Wheat	
Amino acid					
Arginine[x]	0.84*d*	1.18*c*	1.44*b*	1.56*a*	0.02
Cysteine[x]	0.43*d*	0.56*c*	0.72*b*	0.76*a*	0.01
Histidine[x]	0.42*d*	0.69*c*	0.79*b*	0.82*a*	0.01
Isoleucine[x]	0.61*d*	0.93*c*	1.23*b*	1.30*a*	0.01
Leucine[x]	1.17*d*	3.02*a*	2.67*b*	2.54*c*	0.02
Lysine[x]	0.41*c*	0.55*a*	0.49*b*	0.46*b*	0.02
Methionine[x]	0.28*c*	0.52*b*	0.58*a*	0.58*a*	0.01
Phenylalanine[x]	0.88*d*	1.30*c*	1.74*b*	1.90*a*	0.01
Threonine[x]	0.46*c*	0.82*b*	0.97*a*	0.99*a*	0.01
Tryptophan[x]	0.21*c*	0.20*c*	0.32*b*	0.38*a*	0.01
Valine[x]	0.78*d*	1.33*c*	1.61*b*	1.67*a*	0.01
Digestible energy					
Ileal[x]	3224*b*	3671*a*	3495*ab*	3406*ab*	82.1
Total tract[x]	3807*b*	4292*a*	4038*b*	4019*b*	73.4
Phosphorus[x]	0.06*b*	0.48*a*	0.56*a*	0.59*a*	0.04

[z]Means are least-square means for the four feedstuffs.

[y]Derived from the combined fermentation of wheat and corn in a 4:1 ratio.

[x]Wheat differs from the three DDGS ($P < 0.05$).

a-d Within a row, means without a common letter differ ($P < 0.05$).

Table 8. Intake, excretion and retention of dry matter, N and P of grower-finisher pigs fed a wheat-control diet or diets containing 40% corn, wheat/corn, or wheat distiller's dried grains with solubles (DM basis)

Variable[z]	Wheat control	Distiller's dried grains with solubles			Pooled SEM
		Corn	Wheat/corn[y]	Wheat	
DM intake (g d^{-1})	1780	1838	1885	1796	35.2
DM excretion (g d^{-1})[x]	237*b*	381*a*	391*a*	360*a*	12.2
DM excretion (%)[x]	13.4*b*	20.7*a*	20.8*a*	20.1*a*	0.62
N intake (g d^{-1})[x]	55.4*c*	69.5*b*	83.7*a*	86.6*a*	1.53
N excretion (g d^{-1})					
Faeces[x]	6.1*d*	11.3*c*	14.5*a*	13.0*b*	0.48
Urine[x]	29.7*c*	32.7*bc*	40.7*ab*	44.7*a*	3.04
Total[x]	35.7*b*	44.1*b*	55.2*a*	57.7*a*	2.94
N retention (g d^{-1})[x]	19.7	25.4	28.6	28.9	2.75
N retention (%)	35.6	36.4	33.9	33.2	3.69
P intake (g d^{-1})[x]	11.4[c]	15.2[b]	16.6[a]	16.6[a]	0.29
P excretion (g d^{-1})					
Faeces[x]	6.9*b*	8.5*a*	8.4*a*	8.4*a*	0.29
Urine[x]	1.1*b*	2.0*a*	2.7*a*	2.7*a*	0.20
Total[x]	8.0*b*	10.5*a*	11.0*a*	11.1*a*	0.33
P retention (g d^{-1})[x]	3.4*b*	4.6*a*	5.6*a*	5.6*a*	0.27
P retention (%)	29.8	30.6	33.5	33.5	1.73

[z]Means are least-square means for the four diets.

[y]Derived from the combined fermentation of wheat and corn in a 4:1 ratio.

[x]Wheat differs from the three DDGS ($P < 0.05$).

a-d Within a row, means without a common letter differ ($P < 0.05$).

Table 9. Growth performance of grower-finisher pigs fed a wheat-control diet or diets containing 25% corn, wheat/corn, or wheat distiller's dried grains with solubles

Variable[z]	Wheat control	Distiller's dried grains with solubles			Pooled SEM
		Corn	Wheat/corn[y]	Wheat	
Body weight (kg)					
d 0	51.70	51.88	53.39	51.17	0.44
d 7	60.19	59.58	59.04	59.45	0.44
d 14	67.01	65.99	65.83	65.78	0.44
d 21	74.33	72.30	72.22	72.33	0.44
d 28	81.31*a*	78.89*ab*	78.77*b*	78.89*ab*	0.44
d 35[x]	88.06*a*	85.82*ab*	85.39*b*	85.70*ab*	0.44
ADG (kg d^{-1})					
d 0 to 7	1.136	1.056	1.011	1.024	0.03
d 8 to 14	0.982	0.922	0.959	0.920	0.03
d 15 to 21	1.056	0.906	0.899	0.950	0.03
d 22 to 28	1.004	0.950	0.923	0.948	0.03
d 29 to 35	0.972	0.996	0.933	0.990	0.03
d 0 to 35[x]	1.030*a*	0.966*ab*	0.945*b*	0.967*ab*	0.03
ADFI (kg d^{-1})					
d 0 to 7	2.455	2.294	2.212	2.309	0.05
d 8 to 14	2.723	2.608	2.558	2.475	0.05
d 15 to 21	2.823	2.618	2.676	2.687	0.05
d 22 to 28	2.943*a*	2.802*ab*	2.664*b*	2.863*ab*	0.05
d 29 to 35	2.973	2.880	2.928	2.925	0.05
d 0 to 35[x]	2.784*a*	2.640*b*	2.607*b*	2.651*b*	0.05
Feed Efficiency					
d 0 to 7	0.462	0.460	0.358	0.445	0.01
d 8 to 14	0.362	0.355	0.375	0.377	0.01
d 15 to 21	0.376	0.347	0.335	0.355	0.01
d 22 to 28	0.340	0.341	0.360	0.332	0.01
d 29 to 35	0.328	0.349	0.320	0.342	0.01
d 0 to 35	0.373	0.371	0.370	0.370	0.01

[z]Means are least-square means for the four diets.

[y]Derived from the combined fermentation of wheat and corn in a 4:1 ratio.

[x]Wheat differs from the three DDGS ($P < 0.05$).

a-b Within a row, means without a common letter differ ($P < 0.05$).

Appendix 2b. Erratum. Nutritional value of wheat and corn distiller's dried grain with solubles: digestibility and digestible contents of energy, amino acids and phosphorus, nutrient excretion and growth performance of grower-finisher pigs.

In the previous paper (Appendix 1), the reported values in Tables 5, 6, and 7 were for the experimental diets, and not for the four feedstuffs as indicated in the original table headings. The correct values for the four feedstuffs are reported below.

The main outcome of the corrected values is that the nutritional value of old-style wheat DDGS is lower than the parent wheat.

Table 5. Apparent ileal digestibility (%) of energy and amino acids and total tract digestibility (%) of energy and P in wheat, and corn, wheat/corn, and wheat distiller's dried grains with solubles measured in grower-finisher pigs

Variable[z]	Wheat	Distiller's dried grains with solubles			Pooled SEM
		Corn	Wheat/corn[y]	Wheat	
Ileal digestibility (%)					
Energy[x]	71.8*a*	62.0*b*	60.0*b*	58.0*b*	1.63
Amino acid					
Arginine[x]	87.9*a*	83.3*b*	83.1*b*	84.2*b*	1.01
Cysteine[x]	84.1*a*	69.5*b*	73.8*b*	71.7*b*	1.22
Histidine[x]	87.6*a*	76.4*b*	76.1*b*	76.2*b*	1.08
Isoleucine[x]	83.5*a*	73.1*b*	76.8*b*	76.2*b*	1.07
Leucine[x]	85.2*a*	84.1*a*	83.0*ab*	81.4*b*	0.72
Lysine[x]	70.6*a*	53.7*b*	54.6*b*	45.9*c*	2.07
Methionine[x]	85.0*a*	83.5*ab*	83.8*ab*	80.8*b*	0.91
Phenylalanine[x]	87.9*a*	80.3*b*	85.2*a*	85.5*a*	0.77
Threonine[x]	73.7*a*	66.3*b*	74.9*a*	72.2*a*	1.04
Tryptophan[x]	85.1*a*	76.1*b*	77.5*b*	80.1*ab*	1.79
Valine[x]	86.0*a*	80.6*b*	84.2*a*	83.6*a*	0.81
Total[x]	85.5*a*	74.4*c*	78.6*b*	78.3*b*	0.92
Total tract digestibility (%)					
Energy[x]	84.8*a*	71.5*b*	67.1*b*	68.3*b*	1.39
Phosphorus[x]	14.8*b*	67.4*a*	65.9*a*	61.9*a*	4.15

[z]Means are least-square means for the four feedstuffs.

[y]Derived from the combined fermentation of wheat and corn in a 4:1 ratio.

[x]Wheat differs from the three DDGS ($P < 0.05$).

a-c Within a row, means without a common letter differ ($P < 0.05$).

Table 6. Standardized ileal digestibility (%) of amino acids in wheat, and corn, wheat/corn, and wheat distiller's dried grains with solubles measured in grower-finisher pigs

		Distiller's dried grains with solubles			Pooled
Amino acid[z]	Wheat	Corn	Wheat/corn[y]	Wheat	SEM
Arginine[x]	88.3*a*	83.6*b*	83.3*b*	84.4*b*	1.01
Cysteine[x]	84.5*a*	69.8*b*	74.0*b*	71.9*b*	1.22
Histidine[x]	88.0*a*	76.7*b*	76.3*b*	76.4*b*	1.07
Isoleucine[x]	84.0*a*	73.4*b*	77.0*b*	76.5*b*	1.06
Leucine[x]	85.5*a*	84.2*a*	83.1*ab*	81.6*b*	0.71
Lysine[x]	71.4*a*	54.2*b*	55.1*b*	46.4*c*	2.08
Methionine[x]	85.3*a*	83.7*ab*	84.0*ab*	81.0*b*	0.91
Phenylalanine[x]	88.2*a*	80.5*c*	85.4*b*	85.6*b*	0.77
Threonine[x]	74.8*a*	66.9*b*	75.4*a*	72.6*a*	1.04
Tryptophan[x]	85.8*a*	76.7*b*	77.9*b*	80.4*b*	1.79
Valine[x]	86.7*a*	80.9*b*	84.5*a*	83.9*a*	0.81

[z]Means are least-square means for the four feedstuffs.

[y]Derived from the combined fermentation of wheat and corn in a 4:1 ratio.

[x]Wheat differs from the three DDGS ($P < 0.05$).

a-c Within a row, means without a common letter differ ($P < 0.05$).

Table 7. Standardized ileal digestible amino acid content (% DM), ileal and total tract digestible energy (kcal kg^{-1} DM) and total tract digestible P (% DM) contents in wheat, and corn, wheat/corn, and wheat distiller's dried grains with solubles measured in grower-finisher pigs

Variable[z]	Wheat	Distiller's dried grains with solubles			Pooled SEM
		Corn	Wheat/corn[y]	Wheat	
Amino acid					
Arginine[x]	0.80*d*	1.11*c*	1.37*b*	1.50*a*	0.02
Cysteine[x]	0.41*d*	0.49*c*	0.66*b*	0.69*a*	0.01
Histidine[x]	0.41*d*	0.63*c*	0.72*b*	0.76*a*	0.01
Isoleucine[x]	0.57*d*	0.84*c*	1.16*b*	1.22*a*	0.01
Leucine[x]	1.12*a*	1.10*a*	1.09*ab*	1.07*b*	0.02
Lysine[w]	0.37*bc*	0.45*a*	0.40*b*	0.34*c*	0.02
Methionine[x]	0.27*c*	0.51*b*	0.56*a*	0.56*a*	0.01
Phenylalanine[x]	0.85*d*	1.22*c*	1.69*b*	1.85*a*	0.01
Threonine[x]	0.41*c*	0.73*b*	0.92*a*	0.93*a*	0.01
Tryptophan[x]	0.20*c*	0.18*c*	0.29*b*	0.35*a*	0.01
Valine[x]	0.73*d*	1.24*c*	1.55*b*	1.60*a*	0.01
Digestible energy					
Ileal	3224*ab*	3381*a*	3154*ab*	3011*b*	82.1
Total tract	3807*a*	3900*a*	3527*b*	3548*b*	73.4
Phosphorus[x]	0.06*b*	0.58*a*	0.68*a*	0.68*a*	0.04

[z]Means are least-square means for the four feedstuffs.

[y]Derived from the combined fermentation of wheat and corn in a 4:1 ratio.

[x]Wheat differs from the three DDGS ($P < 0.05$).

a-d Within a row, means without a common letter differ ($P < 0.05$).

Appendix 3. Effect of xylanase supplementation of diets containing wheat distiller's dried grains with solubles on energy, amino acid and phosphorus digestibility and growth performance of grower-finisher pigs

Abstract

Wheat-based diets with or without wheat distiller's dried grains with solubles (DDGS) were tested with or without supplementary xylanase (4,000 U kg^{-1} feed) in a 2 x 2 factorial arrangement. In eight ileal-cannulated barrows, xylanase improved the apparent ileal digestibility of energy and threonine in wheat ($P < 0.05$) but not in wheat DDGS diets ($P > 0.10$). Xylanase did not affect total tract digestibility of energy or P ($P > 0.10$). In 72 grower-finisher pigs, xylanase did not increase growth performance ($P > 0.10$). The differential response of supplementary xylanase to wheat versus wheat DDGS diets indicates that the arabinoxylans in wheat DDGS did not match the specific xylanase activity.

Introduction

Distiller's dried grains with solubles (DDGS) produced from wheat is available in western Canada for inclusion in swine feeds. During the fermentation process, most of the cereal starch is consumed, producing ethanol and carbon dioxide. The remaining fibre, protein, and fat are concentrated. Arabinoxylans are the predominant component of fibre or non-starch polysaccharide (NSP) in wheat and wheat DDGS (Widyaratne and Zijlstra 2007).

The inverse relationship between NSP content and nutrient digestibility in pigs has been well documented. Supplemental xylanase may hydrolyze arabinoxylans and thereby increase energy digestibility of wheat (Diebold et al. 2004) and wheat by-products from dry milling (Nortey et al. 2007). The ability of xylanase to improve nutrient digestibility of a wheat by-product that has undergone fermentation and subsequent drying is not known.

The hypothesis was that the nutritional value of wheat DDGS can be enhanced using supplementary xylanase, by improving nutrient digestibility or feed intake. The objectives were to determine the effects of supplementing xylanase in wheat and wheat DDGS diets on digestibility of energy, amino acids and P and on growth performance of grower-finisher pigs.

Materials and Methods

The animal protocols were approved by the University of Saskatchewan Committee on Animal Care and Supply, followed principles established by the Canadian Council on Animal Care (1993), and were conducted at Prairie Swine Centre Inc. (Saskatoon, SK). In two experiments, wheat-based diets with or without wheat DDGS were tested with or without supplemental xylanase (4000 units kg^{-1} of feed; Danisco Animal Nutrition, Marlborough, UK) as a 2 x 2 factorial arrangement. The wheat DDGS and originating Canada Prairie Spring wheat were obtained from an ethanol plant (Mohawk Canada, Minnedosa, MB) to compare chemical characteristics directly. Hard Red Spring wheat was obtained via a commercial mill.

In Experiment 1, Hard Red Spring wheat was considered the sole source of energy and amino acids in wheat-based diets, whereas in the wheat DDGS-diets, 40% of wheat DDGS was

included as an energy and amino acid source by replacing wheat [see Table 1 in Widyaratne and Zijlstra (2007)]. Chromic oxide was included as an exogenous digestibility marker and diets were fortified to meet or exceed vitamins and mineral requirements [National Research Council (NRC) 1998]. In a double 4 x 4 Latin square, eight barrows (29.4 ± 2.0 kg; PIC Canada Ltd., Airdrie, AB) were fitted with a T-cannula at the distal ileum, providing eight observations per diet. Each 11-d period consisted of a 6-d acclimation to diets followed by a 3-d collection of faeces and 2-d collection of ileal digesta. Pigs were housed in individual metabolism pens (Widyaratne and Zijlstra 2007). The room was maintained within the thermo-neutral zone of the pigs, with a 14-h light (0700 to 2100) cycle. Diets were provided in wet-mash form, in a 1:1 water to mash ratio. Feed allowance was 2.6 x the maintenance requirement for energy [2.6 x 110 kcal digestible energy (DE) kg^{-1} body $weight^{0.75}$; NRC 1998]. Diets were fed in two equal meals at 0800 and 1600. Pigs had free access to water. Faeces were collected for 3 d twice per day (0800 and 1600) using plastic bags fixed around the anus. Digesta samples were collected in 4% formic acid every 2 h for 10 h d^{-1} during 2 d, using plastic bags affixed to the open barrel of the T-cannula. Collected faeces and digesta were pooled per pig observation and stored at –20°C.

In Experiment 2, wheat, field pea, and soybean meal were main ingredients in the wheat diet [see Table 2 in Widyaratne and Zijlstra (2007)]. In the wheat DDGS diet, 25% of wheat DDGS was included by replacing a portion of wheat, soybean meal, and dicalcium phosphate. Diets were formulated to meet or exceed the requirements for amino acids and other nutrients (NRC 1998) to 3.375 Mcal DE kg^{-1} and 2.50 g standardized ileal digestible lysine $Mcal^{-1}$ DE. Other essential amino acids were formulated as a ratio to lysine (NRC 1998). The four diets were fed to 72 grower-finisher pigs (36 barrows and gilts; 49.8 ± 3.2 kg; PIC Canada Ltd., Winnipeg, MB), randomized within gender, and housed individually. Diets were each fed to nine barrows and nine gilts, for 18 observations per diet. The 6-wk study had a 1-wk adaptation to the pen followed by 5-wk feeding of experimental diets. Pens had fully-slatted concrete flooring, a single-space feeder, and a nipple-drinker. The room was maintained within the thermo-neutral zone of the pigs, with a 14-h light (0700 to 2100) cycle. Diets were provided as a dry mash; diets and water were supplied ad libitum. Pigs were weighed on d 0 and 35 and feed disappearance was measured to calculate ADG, average daily feed intake (ADFI), and feed efficiency (G:F).

For Experiment 1, samples were ground through a 1-mm screen and analysed for DM by drying at 135°C for 2 h (method 930.15; AOAC 2006). Feed, faeces and digesta were analysed for chromic oxide by spectrophotometry and gross energy by bomb calorimetry. Ingredient, feed and faeces were analysed for P using a nitric-perchloric acid digestion. Ingredient, feed and digesta were analysed for amino acids (method 982.30E; AOAC 2006) and available lysine (method 975.44; AOAC 2006). Ingredients were analyzed for crude protein (CP; method 988.05; AOAC 2006), crude fat (method 954.02; AOAC 2006), neutral detergent fibre using a fibre analyzer (model ANKOM^{200}, Ankom Technology, Fairport, NY) and Na sulphite and α-amylase, inositol hexaphosphate (phytate) and lower inositol phosphates, by high performance liquid chromatography, and NSP and constituent sugars by gas-liquid chromatography.

Nutrient digestibility was calculated using the indicator method. Pig was the experimental unit. The apparent total tract digestibility (ATTD) of energy and DE content of feedstuffs was calculated using the difference method. Variables were analysed by analysis of variance using the MIXED procedure (SAS, SAS Institute, Inc. Cary, NC). Means were reported as least-square means. The model for Experiment 1 included effects of diet, xylanase, and diet x xylanase and for Experiment 2 also included initial body weight as a covariate. In cases of interactions (or

trends), means were separated using the probability of difference. Overall, $P < 0.05$ was significant, trends ($0.05 < P < 0.10$) were reported, and $P > 0.10$ was considered non-significant.

The content of CP, crude fat, neutral detergent fibre, and P was more than double for wheat DDGS than the parent wheat (Table 1); however, phytate content was 45% lower for wheat DDGS. Wheat DDGS but not wheat contained the lower inositol phosphate forms of phytate. Lysine and threonine content was higher in wheat DDGS than wheat, but lysine availability averaged 91% for the wheat samples and was 69% for wheat DDGS. The constituent sugars of NSP, arabinose and xylose, were higher in wheat DDGS than wheat.

Results

Diet and xylanase interacted for AID of energy and threonine ($P < 0.05$; Table 2), and tended to interact for lysine ($P < 0.10$). Xylanase improved the AID of energy and threonine for wheat by 16 and 9%, respectively ($P < 0.05$), but not for wheat DDGS ($P > 0.10$). The ATTD of energy was 8% higher ($P < 0.05$) for the wheat than the wheat DDGS diet; xylanase did not affect ATTD of energy ($P > 0.10$). Total tract DE content tended to be 6% higher ($P < 0.10$) for the wheat DDGS than wheat diet; xylanase did not affect total tract DE content ($P > 0.10$). The ATTD of P was 60% lower for wheat than for wheat DDGS diet ($P < 0.05$), and was not affected by xylanase ($P > 0.10$). The ATTD of energy was higher for wheat than wheat DDGS ($P < 0.05$; 79.1 vs. 66.7%), but their DE content was not different ($P > 0.10$; 3.67 vs. 3.55 Mcal kg^{-1}).

Final body weight tended to be higher for pigs fed wheat than pigs fed wheat DDGS diets ($P = 0.06$; Table 3). Neither xylanase nor a diet x xylanase interaction affected final body weight ($P > 0.10$). For d 0 to 35, ADG of pigs fed wheat was 10% higher than of pigs fed wheat DDGS diets ($P < 0.05$). A diet x xylanase interaction affected ADFI ($P < 0.05$); xylanase reduced ADFI of pig fed wheat ($P < 0.05$) but not of pig fed wheat DDGS diets. Feed efficiency was higher for wheat than wheat DDGS diets ($P < 0.05$). Xylanase did not affect feed efficiency ($P > 0.10$).

Discussion

In the present study, wheat and wheat DDGS diets were contrasted for nutrient digestibility and growth responses to supplemental xylanase. Xylanase increased nutrient digestibility for wheat but not wheat DDGS diets. Xylanase did not affect growth responses.

Wheat DDGS had a higher protein, fat, and fibre content than wheat, similar to previous studies (Nyachoti et al. 2005; Widyaratne and Zijlstra 2007). Starch removal via fermentation, and perhaps the yeast used for fermentation, increased the content of remaining constituents in wheat DDGS, except phytate, which was higher in wheat. The wheat samples differed in nutrient profile, but wheat composition varies widely among samples.

The CP and amino acid content of wheat DDGS can vary based on the wheat used for ethanol production (Nyachoti et al. 2005). The CP content in wheat DDGS was 7%-units lower than previously (Widyaratne and Zijlstra 2007), because the wheat DDGS originated from Canada Prairie Spring wheat, which has a lower CP content, rather than Hard Red Spring wheat. Consequently, the content of amino acids in wheat DDGS was also lower than previously, except for lysine. As a percentage of CP, lysine content in wheat DDGS was 2.17% instead of 1.62% previously (Widyaratne and Zijlstra 2007), an indication that lysine quality of wheat DDGS was higher in the present study. Still, lysine remained clearly damaged in wheat DDGS (Lan et al. 2008), because lysine availability of lysine was markedly lower than in wheat.

The ATTD of energy was higher for wheat than wheat DDGS diets, even though the AID of energy did not differ, similar to Widyaratne and Zijlstra (2007). The data provides strong evidence that the fibre fraction in wheat DDGS was drastically different than in wheat, because hindgut utilization of energy was higher for the wheat than wheat DDGS diet. Increasing wheat DDGS levels from 0 to 25% linearly reduced ATTD of energy in diets fed to grower pigs (Thacker 2006), providing further evidence that energy in wheat DDGS is digested less well than energy in wheat, with NSP in wheat DDGS likely as a contributing factor. The DE content of wheat DDGS was equal to previous data (3.55 Mcal kg^{-1} DM; Widyaratne and Zijlstra 2008).

The ATTD of P was higher for wheat DDGS than wheat diets (Nyachoti et al. 2005; Widyaratne and Zijlstra 2007). The wheat DDGS in the present study contained less intact phytate and more of less complex forms of phytate than wheat, likely due to breakdown of phytate during fermentation. Inclusion of wheat DDGS in swine diets may include environmental benefits for management of P excretion in swine manure.

Inclusion of 25% wheat DDGS in swine diets reduced growth performance in the present study. Feeding wheat DDGS to group-housed grower pigs may reduce growth due to reduced ADFI or feed efficiency (Thacker 2006; Widyaratne and Zijlstra 2007). In the present study with individually-housed pigs, reduced ADG was caused solely by reduced feed efficiency.

In the present study, xylanase improved the AID of energy and threonine of wheat but not of wheat DDGS diets. The response of wheat to xylanase was consistent with the improved AID of amino acids in diets containing 98% wheat supplemented with up to 16,500 U g^{-1} xylanase fed to grower pigs (Barrera et al. 2004). Supplementation of 4,000 U g^{-1} xylanase tended to increase DM digestibility of wheat-based diets (Mavromichalis et al. 2000). Similarly, supplementation of xylanase to diets based on wheat and wheat millrun improved AID of amino acids and energy and ATTD of energy in grower pigs (Nortey et al. 2007). The xylanase thus hydrolyzes wheat arabinoxylans in either ground wheat or dry processed wheat by-products.

The lack of response in nutrient digestibility of wheat DDGS to xylanase was puzzling. The analyzed content of arabinoxylans is higher in wheat DDGS than in wheat (Widyaratne and Zijlstra 2007), indicating that a xylanase should have been effective. However, wheat is exposed to fermentation and drying processes that may change the nature of NSP, including arabinoxylans, thereby preventing xylanase from being effective. For example, the ratio of xylose to arabinose was 1.55 to 1 in Canada Prairie Spring wheat yet 1.60 to 1 in wheat DDGS, indicating a different polymerization of NSP. As a result, the substrate for xylanase, the original wheat arabinoxylans, might not be the factor limiting nutrient digestibility. Finally, unidentified factors associated with wheat DDGS may hinder effectiveness of xylanase.

Supplementary xylanase did not improve ADG of pigs. In pigs fed a protein-deficient wheat-diet, xylanase tended to improve ADG (Barrera et al. 2004) whereas xylanase did not improve ADG of pigs fed a balanced diet (Mavromichalis et al. 2000). Growth responses to xylanase supplementation of diets containing wheat NSP are not as consistently positive as nutrient digestibility responses (Nortey et al. 2007). Xylanase reduced ADFI but not ADG of pigs fed the wheat diet in the present study, indicating that improved nutrient digestibility was balanced with reduced ADFI. The breakdown of arabinoxylans may have solubilised extra NSP, thereby reducing digesta passage rate and ADFI. Xylanase did not act similarly for the wheat DDGS diet, providing further evidence that NSP in wheat DDGS is different than in the wheat.

In conclusion, the differential response of supplementary xylanase to wheat versus wheat DDGS diets indicates that the specific xylanase activity used in the present study matches the

arabinoxylans in wheat but not in the wheat DDGS. Further studies are required to improve nutrient digestibility in pigs fed diets based on wheat DDGS or to identify factors associated with reduced nutrient digestibility of wheat DDGS.

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Table 1. Chemical characteristics of wheat used in the basal diet, wheat used to produce the wheat distiller's dried grains with solubles (DDGS), and wheat DDGS of the digestibility study (Experiment 1)

	Wheat[z]		
Variable, % DM	Hard Red Spring	Canada Prairie Spring	Wheat DDGS
Moisture	14.2	15.6	8.9
Gross energy (Mcal kg^{-1} DM)	4.63	4.48	5.32
Crude protein	16.8	13.6	37.3
Crude fat	1.9	1.8	5.0
Neutral detergent fibre	14.9	13.2	38.8
Phosphorus	0.40	0.34	0.99
Phytate[y]	1.08	1.15	0.65
Amino acid			
Lysine	0.56	0.40	0.81
Threonine	0.48	0.37	1.05
Available lysine	0.49	0.37	0.56
Total NSP	11.70	8.16	16.65
Xylose	4.82	2.89	8.06
Arabinose	3.04	1.86	4.89

[z]Hard Red Spring was used in basal diet and Canada Prairie Spring produced the wheat DDGS.

[y]Apart from phytate (inositol hexaphosphate), wheat DDGS but not wheat also contained the following inositol phosphates (IP, %): IP2, 0.20; IP3, 0.30,; IP4, 0.22; IP5, 035.

Table 2. Effect of xylanase supplementation of apparent energy, lysine, threonine, and phosphorus digestibility of diets containing wheat and wheat distiller's dried grains with solubles measured in grower-finisher pigs (Experiment 1)

	Wheat		Wheat DDGS		Pooled	*P* value		
Variable[z]	- xylanase	+ xylanase	- xylanase	+ xylanase	SEM	Diet	Xylanase	Interaction
Ileal digestibility (%)								
Energy	57.5*b*	66.8*a*	59.6*ab*	57.3*b*	3.54	0.163	0.153	0.026
Lysine	60.3*ab*	64.7*a*	61.3*ab*	58.6*b*	2.55	0.220	0.646	0.062
Threonine	56.5*b*	65.3*a*	68.6*a*	65.1*a*	2.70	0.044	0.330	0.025
Total tract digestibility (%)								
Energy	79.4	78.8	73.1	73.2	2.21	0.017	0.903	0.891
Phosphorus	19.29	19.85	49.26	48.41	4.03	<0.001	0.973	0.871
Digested energy (Mcal kg^{-1} DM)								
Ileal	2.65*b*	3.09*a*	3.16*a*	3.05*a*	0.18	0.087	0.209	0.038
Total tract	3.68	3.65	3.87	3.89	0.11	0.066	0.904	0.904

[z]Means are least-square means based on eight observations per treatment mean.

a-b Within a row for each factor, means without a common letter differ ($P < 0.05$).

Table 3. Growth performance and body weight of grower-finisher pigs fed diets containing wheat or 25% wheat distiller's dried grains with solubles, with and without supplementary xylanase (Experiment 2)

	Wheat		Wheat DDGS		Pooled	*P* value		
Variable[z]	- Xylanase	+ Xylanase	- Xylanase	+ Xylanase	SEM	Diet	Xylanase	Interaction
Body weight (kg)								
Day 0	50.02	49.78	49.99	49.44	0.53	0.550	0.218	0.622
Day 35	84.53	83.36	81.06	80.85	0.75	0.058	0.660	0.757
Growth performance (day 0 to 35)								
ADG (kg d^{-1})	1.02	0.99	0.92	0.91	0.04	0.022	0.585	0.749
ADFI (kg d^{-1})	2.89*a*	2.62*b*	2.62*b*	2.70*b*	0.06	0.124	0.117	0.004
Feed efficiency	0.36	0.37	0.31	0.28	0.03	0.032	0.929	0.465

[z]Means are least-square means based on 18 observations per treatment mean.

a-b Within a row, means without a common letter differ ($P < 0.05$).

Appendix 4. Voluntary Feed Intake, Growth Performance, and Total-Tract Energy Digestibility for Corn-Based Diets Containing Dried Corn Distiller's Grains with Solubles Fed to Group-housed Grower Pigs with or without Supplemental Xylanase

Summary

Corn dried distiller's grain with solubles (DDGS) is becoming an abundant feed ingredient in North America, yet its chemical characteristics and nutritional value and especially its response to supplemental enzymes are poorly characterized. The main objective of the experiment was to determine if Y5-xylanase improves voluntary feed intake, growth performance, and total-tract energy digestibility of a corn-based diet with corn DDGS limiting in DE content. Five diets were tested in 30-kg grower-finisher pigs for 35 days. The diets were (1) positive control diet, 3.50 Mcal DE; (2) negative control, 3.40 Mcal DE; (3) negative control + 42.5 g/MT Y5 xylanase, 3.40 Mcal DE; (4) negative control + 85 g/MT Y5 xylanase, 3.40 Mcal DE; and (5) negative control + 170 g/MT Y5 xylanase, 3.40 Mcal DE. The actual reduction in calculated DE content from the positive to negative control was 48 kcal/kg DM. Xylanase supplementation improved diet DE content ($P < 0.05$); xylanase tended to improve DE content quadratically ($P < 0.10$) but not linearly ($P > 0.10$). Overall, ADG was 0.96 kg/d and ADFI was 1.90 kg/d and were therefore both higher than expected on commercial operations. Overall, pigs fed the positive and negative control diets did not differ in performance variables ($P > .10$). Xylanase did not improve ADG or ADFI, but xylanase supplementation improved feed efficiency quadratically ($P < 0.05$).

Introduction

Corn dried distiller's grain with solubles (DDGS) is becoming an abundant feed ingredient in North America, yet its chemical characteristics and nutritional value and especially its response to supplemental enzymes are poorly characterized.

Corn DDGS should contain higher concentrations of NSP, oil, and protein than the feedstock corn due to the breakdown of corn starch during the fermentation process to produce ethanol. Still, the nutritional value of corn DDGS currently produced remains controversial. For example, NRC (1998) estimates a DE content of 3,450 kcal/kg DM, whereas some more recent experiments estimate a DE content to be as high as 4,010 kcal/kg DM (Shurson 2002).

A recently completed trial at PSC suggests that a DE content for corn DDGS of 3,890 kcal/kg DM or 3,430 kcal/kg as is might be more appropriate (Widyaratne et al. 2004). For diet formulations for this protocol, a DE content of 3,430 kcal/kg as is for corn DDGS was therefore used. Corn DDGS was be limited to 20% in the diet for grower pigs.

Corn contains xylans and corn DDGS should contain xylans as well, most likely at an increased level compared to corn. The expected high concentrations of xylans may limit nutrient digestibility and may warrant that supplemental xylanase is included in swine diets containing corn DDGS.

The hypothesis of the study is that Corn contains xylans and corn DDGS should contain xylans as well, most likely at an increased level compared to corn. The expected high

concentrations of xylans may limit nutrient digestibility and may warrant that supplemental xylanase is included in swine diets containing corn DDGS.

The objectives of the project are:

- To determine if Y5-xylanase improves voluntary feed intake, growth performance, and total-tract energy digestibility of a corn-based diet with corn DDGS limiting in DE content.
- To determine whether the Y5-xylanase response is dose-respondent.
- To determine whether the Y5-xylanse improves voluntary feed intake, growth performance, and total-tract energy digestibility of a diet limiting in DE content back to levels of a diet not limiting in DE content.

Materials and Methods

Experimental Design

Five diets were tested in 30-kg grower-finisher pigs for 35 days. The diets were:

- AA positive control 3.50 Mcal DE
- BB negative control 3.40 Mcal DE
- CC negative control + 42.5 g/MT Y5 3.40 Mcal DE
- DD negative control + 85 g/MT Y5 3.40 Mcal DE
- EE negative control + 170 g/MT Y5 3.40 Mcal DE

The 168 g/MT of Y5 was equivalent to 0.5 kg/MT of Porzyme 9302 or 1 kg/MT of Porzyme 9300. The specific batch of Y5 had lot number Y5-04-129 and an activity level of 26,000 U/g.

In two rooms, 200 grower pigs were housed in 40 pens, with six pigs per pen, for a total of eight pens per diet. Barrows and gilts were penned separately.

Voluntary feed intake and growth performance were measured every 14 days after starting the experiment and feces were collected to measure the achieved DE content.

Facilities and Equipment

Two rooms containing 20 pens each were used for the experiment for five weeks each. Per room, 20 out of the available 20 pens were used to reach 40 observations in total or 8 per diet. All pens with a room (among rooms 140 to 148) therefore housed experimental pigs. The pens housed six pigs per pen. Extra pigs out of the same weaning group were housed elsewhere.

The pen flooring was fully-slotted concrete and the siding was sturdy PVC-planking. A single-space feeder was located at the front of the pen and a nipple-drinker was located at the back of the pen. Diets were stored in bulk in bins, one bin per diet.

Ingredient and Nutrient Composition of Diets

The diets were formulated to meet requirements for amino acids, vitamins and minerals (Table 4.1). Acid-insoluble ash (1% Celite) was added to the diets as a marker.

A positive control diet (diet AA; 1 or 2) based on corn was formulated to a regular DE content for grower pigs (3.50 Mcal DE/kg as fed) with 20% DDGS.

Compared the regular diet formulation, the DE content has been reduced by 100 kcal/kg to 3.40 Mcal DE/kg as fed for the negative control and the three xylanase-supplemented diets (diets

BB, CC, DD, and EE). For diets BB to EE, digestible lysine content was maintained by increasing the amount of lysine per unit of energy (Table 4.1) to allow for improved energy digestibility by xylanase to be expressed as increased protein deposition and therefore ADG. Diets were formulated without a growth promotant.

Diet Mixing and Processing

For the animal experiment, 4,000 kg of each diet were mixed in 2,000-kg batches at the Federated Co-op feedmill, and delivered in bulk to Prairie Swine Centre as pelleted diets.

Premixes of enzymes. The Y-5 xylanase was mixed per 2,000-kg batch into 20 kg of ground corn in a Hobart mixer prior to diet processing.

Samples of ingredients. For the corn, corn DDGS, and SBM, 1-kg samples were taken during diet processing, or immediately prior to diet processing.

Grinding of corn. The corn were ground across a 16/64"-screen in the hammer-mill at Federated Co-op. All corn that is needed for the experimental diets was ground together in advance.

Order of mixing diets. Diets were mixed in the following order: AA, BB, CC, DD, and EE ensuring that the supplemental enzyme could not be included in the control diets, and that enzyme-supplemented diets were processed in order of increasing enzyme concentration.

Pelleting of diets. During pelleting, pelleting temperature did not exceed 90°C, and stayed in the range of 80 to 85°C. Conditioning was as short as possible. Pellet temperature, steam pressure, and PDI were recorded for each of the five diets. Diets were sampled following pelleting for sure.

Feed Management

Diets were provided as dry mash. Pigs had free access to water. Feeders and drinkers were checked daily to ensure free flow of feed and water. For the first days after moving into the room, pigs continued to be fed their regular production diet. The pigs were switched abruptly to experimental diets.

Animal and Diet Randomization

First, for each of the rooms, pigs (PIC) were selected within gender out of a larger, single weaning group based on body weight and ADG (weight per day of age since birth), ensuring that sixty healthy pigs per gender were available. Second, the sixty pigs within gender were sorted by body weight and divided into six weight categories (heavy, heavy-medium, medium-heavy, medium-light, light-medium, and light) with ten pigs in each category. Third, one pig from each of six weight categories was randomly assigned to each of ten pens per gender, resulting in ten pens with six barrows and ten pens with six gilts. Fourth, barrow pens were on one side of the room (pens 1 through 10), whereas gilt pens were on the other side (pens 11 through 20). Finally, one of five diets was randomly assigned to sets of five pens.

Animal Care and Management

The animal care protocol for regular care of grower-finisher pigs (#970019) as approved by the University Committee of Animal Care and Supply of the University of Saskatchewan was valid for the project. Pigs were cared for following PSCI's Standard Operating Procedures.

After selection, pigs were moved into the room and were fed a regular production diet (PSC-3), for a minimum of 3 and a maximum of 7 days, to acclimate the pigs to the room and their pen mates. Pigs were then fed experimental diet for 4 weeks.

Pigs with a health status or body condition that deteriorates beyond acceptance at any time were weighed and removed from the experiment. The reason for removal was noted. The data collected for such animals was partially (for the period the removal occurred) excluded from statistical analyses.

The rooms were maintained within thermo-neutral zone of the pigs, with a 14 hr light (0700 to 2100)/10 hr dark cycle.

Data and Sample Collection Methods

During diet processing, samples of the main ingredients (corn, DDGS, SBM) and the diets were taken. During the animal study, one diet sample per week was collected per diet. Collected feed samples were pooled over the experimental period into one bag per diet, which were stored in a freezer maintained at –20 °C.

Pigs were weighed at the start of the experimental period, at 7, 14, 21, 28, and 35 days after the start of the experiment. All feed was weighed prior to adding to the feeder. Feed was weighed back at each time point that pigs were weighed. Data was recorded on pre-designed form and entered into a network computer within 24-hr after collection to ensure protected data storage.

Feces were collected during the second week of the experiment for 2 days using the grab method. Feces were pooled per pen and stored in a freezer maintained at –20 °C until analyses.

Chemical Analyses

Samples of the main ingredients were analyzed for NSP profile by Danisco. Danisco will analyze diet samples and the enzyme for xylanase activity. A list with samples provided to Danisco will be sent by e-mail to John van Oort, Janet Remus, and Howard Simmins; a hard-copy of the list will be included with the samples.

Feces samples were homogenized, sub-sampled, and freeze-dried. Diet and feces samples were ground through a 1-mm screen. Diets and feces were analyzed for gross energy using a bomb calorimeter, dry matter, and acid-insoluble ash. Energy digestibility was calculated using the indirect method using acid-insoluble acid concentrations in diet and feces.

Statistical Analyses

To compare differences in voluntary feed intake, growth performance and energy digestibility among diets, data were analyzed by ANOVA using the general linear models procedure within SAS. Pen was considered the experimental unit. The statistical model included the following factors: diet, gender and diet x gender. Results were reported as least-square means.

Results and Discussion

Feed Processing

The measured pelleting temperature remained below the maximum of 90°C (Table 4.2), suggesting that pelleting temperature would not have inactivated the xylanase. This will be confirmed using laboratory analyses. The results of the pellet durability index (PDI) analyses indicate that pellet quality was reasonable, considering that corn and corn DDGS together made up more than 70% of the diets.

Energy Digestibility and DE Content

Energy digestibility was not affected by diet ingredient composition ($P > 0.10$; positive versus negative control) or xylanase supplementation ($P > 0.10$; Table 4.3).

The actual, achieved reduction in DE content from the positive to negative control was 48 kcal/kg DM ($P < 0.01$; Table 4.3). Xylanase supplementation to the negative control diet increased DE content by 30 kcal/kg DM ($P < 0.05$). Xylanase supplementation tended to improve DE content quadratically ($P < 0.10$), but not linearly ($P > 0.10$).

Growth Performance

Overall, ADG was 0.96 kg/d and ADFI was 1.90 kg/d and were therefore both higher than expected on commercial operations. The reduction in dietary DE content for the negative control diet did not result in a reduction of ADFI or ADG for pigs fed the negative control diet compared to the positive control diet ($P > 0.10$; Table 4.4). Pigs fed the negative control diet tended to have a 2% reduced feed efficiency compared to the positive control diet ($P < 0.10$). Numerically, the pigs fed the negative control diet slightly increased their ADFI to compensate for the reduced dietary DE content.

Xylanase did not improve ADG or ADFI for any of the individual weeks of the animal study or for the overall experimental period ($P > 0.10$; Table 4.4). Xylanase supplementation improved feed efficiency quadratically ($P < 0.05$). Overall, the data suggesting a positive effect of xylanase supplementation on feed efficiency is not as strong as the data for diet DE content.

The overall results suggest that the measured diet DE content is a more sensitive measure of changes in calculated DE content than in measured growth performance, even though the actual achieved reduction in DE content was not fully achieved. For future research, it is recommended to target a 150 kcal/kg reduction in DE content between the positive and negative control diets.

Table 1 Ingredient composition and calculated nutrient content of the control diets

	Positive control AA	Negative control [a] BB
Ingredients (%)		
Corn	51.27	57.96
Corn DDGS	20.00	20.00
Soybean meal	23.70	17.30
Canola oil	1.30	-
Dicalcium phosphate	0.40	1.05
Limestone	0.95	1.00
Acid-insoluble ash	1.00	1.00
Salt	0.40	0.40
Vitamin mix	0.40	0.40
Mineral mix	0.40	0.40
L-Lysine-HCl	0.18	0.37
L-threonine	-	0.07
L-tryptophan	-	0.03
DL-methionine	-	0.02
Total	100.00	100.00
Calculated nutrient content		
DE (Mcal/kg)	3.50	3.40
Dig. Lysine (g/Mcal DE)	2.57	2.65
Dig. Lysine (%) [b]	0.90	0.90

[a] For xylanase-supplemented diets, xylanase replaced corn 1:1 (wt:wt). Xylanase (Y-5) was added to the negative control diet at 42.5, 85.0 and 170.0 g/MT of feed to create the three xylanase-supplemented diets.

[b] Other essential amino acids as a ratio to lysine (NRC 1998)

Table 2 Processing characteristics of the five experimental diets for the grower pig study

	Diet				
	Positive	Negative	Xylanase (g/MT)		
Variable	Control	Control	42.5	85.0	170
Particle size					
Mean (μm)					
S_{gw}	Was confirmed to be 800 μm for 16/64"-screen				
Pelleting of diets					
Temp (°C)					
1st measurement	60	60	60	60	60
2nd measurement	61	57	58	57	57
PDI	93	95	93	92	93

Table 3 Energy digestibility and DE content

	Diet						P-value		
	Positive	Negative	Xylanase (g/MT)			Pooled	Positive vs	Negative	Xylanase	
Variable	Control	Control	42.5	85.0	170	SEM	Negative	vs Xylanase	Linear	Quadratic
Energy digestibility, %	82.0	82.3	83.1	82.9	81.9	0.3	0.48	0.26	0.28	0.37
DE content (kcal/kg DM)	3775	3727	3767	3760	3744	12	0.01	0.03	0.39	0.10

Table 4 Growth performance data

	Diet						P-value			
	Positive	Negative	Xylanase (g/MT)			Pooled	Positive vs	Negative	Xylanase	
Variable	Control	Control	42.5	85.0	170	SEM	Negative	vs Xylanase	Linear	Quadratic
Average daily feed intake (kg/d)										
d 0 to 7	1.45	1.48	1.44	1.50	1.49	0.04	0.56	0.97	0.60	0.66
d 8 to 14	1.67	1.74	1.76	1.78	1.81	0.03	0.14	0.31	0.16	0.49
d 15 to 21	1.90	1.93	1.91	1.93	1.97	0.04	0.61	0.92	0.55	0.86
d 22 to 28	2.06	2.07	2.13	2.09	2.14	0.04	0.88	0.29	0.36	0.59
d 29 to 35	2.19	2.22	2.23	2.19	2.22	0.05	0.68	0.96	0.93	0.52
Total: d 0 to 35	1.85	1.89	1.91	1.90	1.93	0.03	0.43	0.52	0.47	0.48
Average daily gain (kg/d)										
d 0 to 7	0.84	0.83	0.80	0.86	0.86	0.02	0.80	0.82	0.22	0.17
d 8 to 14	0.96	1.00	0.98	0.97	0.97	0.02	0.31	0.51	0.49	0.35
d 15 to 21	1.01	0.97	0.97	0.99	1.01	0.03	0.30	0.57	0.33	0.29
d 22 to 28	0.98	1.00	1.01	1.02	1.01	0.02	0.50	0.63	0.72	0.77
d 29 to 35	1.00	0.95	0.94	0.99	0.94	0.04	0.30	0.88	0.95	0.14
Total: d 0 to 35	0.96	0.95	0.94	0.97	0.96	0.01	0.59	0.72	0.40	0.18
Feed efficiency										
d 0 to 7	0.58	0.56	0.55	0.57	0.58	0.01	0.24	0.74	0.19	0.11
d 8 to 14	0.58	0.57	0.57	0.55	0.54	0.01	0.84	0.20	0.06	0.49
d 15 to 21	0.53	0.50	0.50	0.51	0.51	0.01	0.01	0.37	0.33	0.03
d 22 to 28	0.47	0.48	0.47	0.49	0.47	0.01	0.53	0.63	0.67	0.85
d 29 to 35	0.46	0.43	0.42	0.45	0.42	0.01	0.17	0.87	0.92	0.06
Total: d 0 to 35	0.52	0.50	0.50	0.51	0.50	0.01	0.07	0.69	0.87	0.02

Appendix 5. Voluntary Feed Intake, Growth Performance, and Total-Tract Energy Digestibility for Wheat and Corn -Based Diets Containing Dried Corn Distiller's Grains with Solubles Fed to Group-housed Grower Pigs with or without Supplemental Xylanase

Summary

Corn dried distiller's grain with solubles (DDGS) is becoming an abundant feed ingredient in North America, yet its chemical characteristics and nutritional value and especially its response to supplemental enzymes are poorly characterized. The main objective of the experiment was to determine if Porzyme 9300-xylanase improves voluntary feed intake, growth performance, and total-tract energy digestibility of a wheat and corn-based diet with corn DDGS limiting in DE content. Five diets were tested in 30-kg grower-finisher pigs for 35 days. The diets were (1) positive control diet, 3.50 Mcal DE; (2) negative control, 3.35 Mcal DE; (3) negative control + 0.25 kg/MT Porzyme 9300 xylanase, 3.35 Mcal DE; (4) negative control + 0.50 kg/MT Porzyme 9300 xylanase, 3.35 Mcal DE; and (5) negative control + 1.0 kg/MT Porzyme 9300 xylanase, 3.35 Mcal DE. The actual reduction in calculated DE content from the positive to negative control was 144 kcal/kg DM. Xylanase supplementation improved energy digestibility and diet DE content linearly ($P < 0.05$). Overall, ADG was 0.95 kg/d and ADFI was 1.91 kg/d and were therefore both higher than expected on commercial operations. Overall, pigs fed the positive and negative control diets did not differ in performance variables ($P > 0.10$). Despite the improvement in DE content, xylanase did not improve growth performance ($P > 0.10$).

Introduction

Corn dried distiller's grain with solubles (DDGS) is becoming an abundant feed ingredient in North America, yet its chemical characteristics and nutritional value and especially its response to supplemental enzymes are poorly characterized.

Corn DDGS should contain higher concentrations of NSP, oil, and protein than the feedstock corn due to the breakdown of corn starch during the fermentation process to produce ethanol. Still, the nutritional value of corn DDGS currently produced remains controversial. For example, NRC (1998) estimates a DE content of 3,450 kcal/kg DM, whereas some more recent experiments estimate a DE content to be as high as 4,010 kcal/kg DM (Shurson 2002).

A recently completed trial at PSC suggests that for corn DDGS a DE content of 3,890 kcal/kg DM or 3,430 kcal/kg as is may be more appropriate (Widyaratne et al. 2004). For diet formulations for this protocol, a DE content of 3,430 kcal/kg as is for corn DDGS was therefore used. Corn DDGS was limited to 20% in the diet for grower pigs.

A second completed trial at PSC suggested that the effect of xylanase on a corn-based diet with corn DDGS was limited; therefore, the addition of additional xylans in the form of wheat arabinoxylans should increase the likelihood of further beneficial effects of xylanase on nutrient digestibility and growth performance.

Corn contains xylans and corn DDGS should thus contain xylans, most likely at an increased level compared to corn. Wheat contains high levels of arabinoxylans among the cereal grains and wheat xylans have been related to a reduced DE content (Zijlstra et al. 1999). The expected

high concentrations of xylans may limit nutrient digestibility and may warrant that supplemental xylanase is included in swine diets based on wheat and corn that also contain corn DDGS.

The hypothesis of the project is that wheat and corn contain xylans and corn DDGS should contain xylans as well, most likely at an increased level compared to corn. The expected high concentrations of xylans may limit nutrient digestibility and may warrant that supplemental xylanase is included in swine diets containing corn DDGS.

The objectives were to:

- To determine if xylanase improves voluntary feed intake, growth performance, and total-tract energy digestibility of a wheat and corn-based diet with corn DDGS limiting in DE content.
- To determine whether the xylanase response is dose-respondent.
- To determine whether the xylanse improves voluntary feed intake, growth performance, and total-tract energy digestibility of a diet limiting in DE content back to levels of a diet not limiting in DE content.

Materials and Methods

Experimental Design

Five diets were tested in 30-kg grower-finisher pigs for 35 days. The diets were:

- AA positive control 3.50 Mcal DE
- BB negative control 3.35 Mcal DE
- CC negative control + 0.25 kg/MT 9300 3.35 Mcal DE
- DD negative control + 0.5 kg/MT 9300 3.35 Mcal DE
- EE negative control + 1 kg/MT 9300 3.35 Mcal DE

The 1 kg/MT of Porzyme 9300 is the regular dose of xylanase.

In two rooms, 200 grower pigs were housed in 40 pens, with five pigs per pen, for a total of eight pens per diet. Barrows and gilts were penned separately. The study is therefore a 2 x 5 factorial arrangement [(barrow, gilt) x five diets)].

Voluntary feed intake and growth performance were measured every 7 days after starting the experiment and feces were collected to measure the achieved DE content.

Facilities and Equipment

Two rooms containing 20 pens each were used for the experiment for up to five weeks each. Per room, 20 out of the available 20 pens were used to reach 40 observations in total or 8 per diet. All pens with a room (among rooms 140 to 148) therefore housed experimental pigs. The pens housed six pigs per pen.

The pen flooring is fully-slotted concrete and the siding is sturdy PVC-planking. A single-space feeder is located at the front of the pen and a nipple-drinker is located at the back of the pen. Diets were stored in bulk in bins, one bin per diet.

Ingredient and Nutrient Composition of Diets

The diets were formulated to meet requirements for amino acids, vitamins and minerals (Table 5.1). Acid-insoluble ash (1% Celite) was added to the diets as a marker.

A positive control diet (diet AA) based on wheat and corn has been formulated to a regular DE content for grower pigs (3.50 Mcal DE/kg) with 20% DDGS.

Compared to the regular diet formulation, the DE content has been reduced by 150 kcal/kg to 3.35 Mcal DE/kg for the negative control and the three xylanase-supplemented diets (diets BB, CC, DD, and EE). For diets BB to EE, digestible lysine content was maintained by increasing the amount of lysine per unit of energy (Table 5.1) to allow for improved energy digestibility by xylanase to be expressed as increased protein deposition and therefore ADG. Diets were formulated without a growth promotant.

Diet Mixing and Processing

For the animal experiment, 4,000 kg of each diet was mixed in 2,000-kg batches at the Federated Co-op feedmill, and delivered in bulk to Prairie Swine Centre as pelleted diets.

Premixes of enzymes. The xylanase was mixed per 2,000-kg batch into 20 kg of ground wheat in a Hobart mixer prior to diet processing.

Samples of ingredients. For the wheat, corn, corn DDGS, and SBM, 1-kg samples were taken during diet processing, or immediately prior to diet processing.

Grinding of corn. The wheat and corn were ground across a 16/64"-screen in the hammer-mill at Federated Co-op. All wheat and corn that is needed for the experimental diets was ground in advance.

Order of mixing diets. Diets were mixed in the following order: AA, BB, CC, DD, and EE ensuring that the supplemental enzyme could not be included in the control diets, and that the enzyme-supplemented diets were processed in order of increasing enzyme concentration.

Pelleting of diets. During pelleting, pelleting temperature did not exceed 90°C, and stayed in the range of 60 to 65°C. Conditioning was as short as possible. Pellet temperature, steam pressure, and PDI were recorded for each of the five diets. Diets were sampled following pelleting for viscosity analyses.

Feed Management

Diets were provided as dry mash. Pigs had free access to water. Feeders and drinkers were checked daily to ensure free flow of feed and water. For the first days after moving into the room, pigs continued to be fed their regular production diet. The pigs were switched abruptly to experimental diets.

Animal and Diet Randomization

First, for each of the rooms, pigs (PIC) were selected within gender out of a larger, single weaning group based on body weight and ADG (weight per day of age since birth), ensuring that sixty healthy pigs per gender were available. Second, the sixty pigs within gender were sorted by body weight and divided into six weight categories (heavy, heavy-medium, medium-heavy, medium-light, light-medium, and light) with ten pigs in each category. Third, one pig from each of six weight categories was randomly assigned to each of ten pens per gender, resulting in ten pens with six barrows and ten pens with six gilts. Fourth, barrow pens were on one side of the room (pens 1 through 10), whereas gilt pens were on the other side (pens 11 through 20). Finally, one of five diets was randomly assigned to sets of five pens.

Animal Care and Management

The animal care protocol for regular care of grower-finisher pigs (#970019) as approved by the University Committee of Animal Care and Supply of the University of Saskatchewan was valid for the project. Pigs were cared for following PSCI's Standard Operating Procedures.

After selection, pigs were moved into the room and were fed a regular production diet (PSC-3), for a minimum of 3 and a maximum of 7 days, to acclimate the pigs to the room and their pen mates. Pigs were then fed experimental diet for 4 weeks.

Pigs with a health status or body condition that deteriorates beyond acceptance at any time were weighed and removed from the experiment. The reason for removal was noted. The data collected for such animals was partially (for the period the removal occurred) excluded from statistical analyses.

The rooms were maintained within thermo-neutral zone of the pigs, with a 14 hr light (0700 to 2100)/10 hr dark cycle.

Data and Sample Collection Methods

During diet processing, samples of the main ingredients (wheat, corn, DDGS, SBM) and the diets were taken. During the animal study, one diet sample per week was collected per diet. Collected feed samples were pooled over the experimental period into one bag per diet, which were stored in a freezer maintained at –20 °C.

Pigs were weighed at the start of the experimental period, at 7, 14, 21, 28, and 35 days after the start of the experiment. All feed was weighed prior to adding to the feeder. Feed was weighed back at each time point that pigs were weighed. Data was recorded on pre-designed form and entered into a network computer within 24-hr after collection to ensure protected data storage.

Feces were collected during the second week of the experiment for 2 days using the grab method. Feces were pooled per pen and stored in a freezer maintained at –20 °C until analyses.

Chemical Analyses

Samples of the main ingredients will be analyzed for NSP profile by Danisco. Danisco will analyze diet samples and the enzyme for xylanase activity. A list with samples provided to Danisco will be sent by e-mail to John van Oort, Janet Remus, and Howard Simmins; a hard-copy of the list will be included with the samples.

Feces samples were homogenized, sub-sampled, and freeze-dried. Diet and feces samples were ground through a 1-mm screen. Diets and feces were analyzed for gross energy using a bomb calorimeter, dry matter, and acid-insoluble ash. Energy digestibility was calculated using the indirect method using acid-insoluble acid concentrations in diet and feces.

Statistical Analyses

To compare differences in voluntary feed intake, growth performance and energy digestibility among diets, data were analyzed by ANOVA using the general linear models procedure within SAS. Pen was considered the experimental unit. The statistical model included the following factors: diet, gender and diet x gender. Results were reported as least-square means.

Results and Discussion

Feed Processing

The measured pelleting temperature remained below the maximum of 80°C (Table 5.2), suggesting that pelleting temperature would not have inactivated the xylanase. This will be confirmed using laboratory analyses. The results of the pellet durability index (PDI) analyses indicate that pellet quality was excellent, considering that corn and corn DDGS together made up 40% of the diets.

Energy Digestibility and DE Content

Energy digestibility was not affected by diet ingredient composition ($P > 0.10$; positive versus negative control). Xylanase supplementation increased energy digestibility linearly ($P < 0.05$; Table 5.3), resulting in a 0.6%-unit higher digestibility with 1 kg/MT of Porzyme 9300 xylanase supplementation.

The actual, achieved reduction in DE content from the positive to negative control was 144 kcal/kg DM ($P < 0.01$; Table 5.3). Xylanase supplementation improved energy digestibility and diet DE content linearly ($P < 0.01$) and resulted in a 31 kcal/kg DM improvement in DE content.

These results suggest strongly that effects of xylanase supplementation can be measured in a digestibility experiment. The results can then be incorporated into least-cost diet formulation by reducing the energy specifications, while resulting in equal performance.

Growth Performance

Overall, ADG was 0.95 kg/d and ADFI was 1.91 kg/d and were therefore both higher than expected on commercial operations. The reduction in dietary DE content for the negative control diet did not result in a meaningful reduction of ADFI or ADG for pigs fed the negative control diet, compared to the positive control diet ($P > 0.10$; Table 5.4). However, numerically slight increases in ADFI and ADG were suggested. Apparently, the reduction in DE content did not affect growth performance of the animals, under the conditions of the experiment.

Xylanase did not improve ADG or ADFI for any of the individual weeks of the animal study or for the overall experimental period ($P > 0.10$; Table 5.4). Despite the improvement in DE content, xylanase did not improve growth performance ($P > 0.10$). These results suggest that beneficial effects of supplemental xylanase on ADG could not be picked up under the conditions of the experiment. It is suggested to measure the effect of supplemental enzymes under true commercial conditions, where ADFI and ADG are generally depressed due to space allowance, pathogen load, and other stressors.

In conclusion, the additional of xylanase to a diet based on wheat, corn, and corn DDGS improved energy digestibility and DE content, but not ADG. For least-cost diet formulation, the specification of DE content of similar diets can be reduced by 31 kcal/kg DM.

Table 1 Ingredient composition and calculated nutrient content of the control diets

	Wheat and corn-based	
	Positive control	Negative control [a]
	AA	BB
Ingredients (%)		
Wheat	40.00	40.00
Corn	14.41	20.25
Corn DDGS	20.00	20.00
Soybean meal	19.05	15.27
Canola oil	2.50	-
Dicalcium phosphate	0.63	0.65
Limestone	0.94	1.20
Acid-insoluble ash	1.00	1.00
Salt	0.40	0.40
Vitamin mix	0.40	0.40
Mineral mix	0.40	0.40
L-Lysine-HCl	0.27	0.38
L-threonine	-	0.05
Total	100.00	100.00
Calculated nutrient content		
DE (Mcal/kg)	3.50	3.35
Dig. Lysine (g/Mcal DE)	2.57	2.69
Dig. Lysine (%) [b]	0.90	0.90

[a] For xylanase-supplemented diets, xylanase replaced wheat 1:1 (wt:wt). Porzyme 9300 was used as xylanase sources and was added to the negative control diet at 0.25, 0.50 and 1.00 kg/MT of feed to create the three xylanase-supplemented diets.

[b] Other essential amino acids as a ratio to lysine (NRC 1998)

Table 2 Processing characteristics of the five experimental diets for the grower pig study

	Diet				
	Positive	Negative	Xylanase (kg Porzyme 9300/MT)		
Variable	Control	Control	0.25	0.50	1.00
Particle size					
Mean (μm)					
S_{gw}	Was confirmed to be 800 μm for 16/64"-screen				
Pelleting of diets					
Temp (°C)					
1st measurement	61	62	58	60	56
2nd measurement	63	61	57	54	58
PDI	92	95	96	95	95

Table 3 Energy digestibility and DE content

Variable	Diet					Pooled SEM	P-value			
	Positive Control	Negative Control	Xylanase (kg Porzyme 9300/MT)				Positive vs Negative	Negative vs Xylanase	Xylanase	
			0.25	0.50	1.00				Linear	Quadratic
Energy digestibility, %	80.4	80.3	80.0	80.7	80.9	0.2	0.72	0.52	0.02	0.22
DE content (kcal/kg DM)	3798	3654	3631	3682	3685	10	0.01	0.30	0.01	0.19

Table 4 Growth performance data

	Diet						P-value			
	Positive	Negative	Xylanase (kg Porzyme 9300/MT)			Pooled	Positive vs	Negative	Xylanase	
Variable	Control	Control	0.25	0.50	1.00	SEM	Negative	vs Xylanase	Linear	Quadratic
Average daily feed intake (kg/d)										
d 0 to 7	1.51	1.50	1.48	1.45	1.57	0.04	0.90	0.97	0.41	0.17
d 8 to 14	1.76	1.74	1.79	1.81	1.83	0.03	0.66	0.07	0.06	0.65
d 15 to 21	1.86	1.85	1.88	1.95	1.91	0.05	0.88	0.31	0.34	0.49
d 22 to 28	1.89	2.02	2.14	2.02	2.06	0.04	0.04	0.37	0.93	0.43
d 29 to 35	2.16	2.30	2.34	2.40	2.38	0.07	0.20	0.44	0.42	0.72
Total: d 0 to 35	1.84	1.88	1.93	1.93	1.95	0.04	0.42	0.28	0.29	0.79
Average daily gain (kg/d)										
d 0 to 7	0.89	0.89	0.89	0.83	0.91	0.03	0.90	0.64	0.95	0.17
d 8 to 14	0.96	0.90	0.97	0.97	0.96	0.02	0.03	0.01	0.07	0.06
d 15 to 21	0.91	0.93	0.93	0.97	0.92	0.02	0.57	0.72	0.84	0.36
d 22 to 28	0.91	0.95	1.03	0.90	0.95	0.03	0.41	0.69	0.45	0.55
d 29 to 35	0.97	1.05	1.01	1.08	1.02	0.04	0.16	0.80	0.95	0.83
Total: d 0 to 35	0.93	0.94	0.97	0.95	0.95	0.02	0.57	0.54	0.90	0.57
Feed efficiency										
d 0 to 7	0.59	0.60	0.60	0.57	0.58	0.01	0.90	0.48	0.23	0.90
d 8 to 14	0.55	0.52	0.54	0.54	0.52	0.01	0.01	0.09	0.83	0.03
d 15 to 21	0.49	0.51	0.50	0.50	0.49	0.01	0.49	0.50	0.47	0.99
d 22 to 28	0.48	0.47	0.48	0.45	0.46	0.01	0.54	0.75	0.32	0.92
d 29 to 35	0.45	0.46	0.43	0.45	0.43	0.01	0.58	0.22	0.36	0.82
Total: d 0 to 35	0.51	0.50	0.50	0.49	0.49	0.01	0.65	0.25	0.09	0.82

Appendix 6. The effect of individual and combined phytase and xylanase supplementation or particle size on the nutrient digestibility of wheat distillers dried grains with solubles in cannulated grower pigs

Abstract

The objective was to study if dietary phytase and xylanase increase digestibility of nutrients in wheat DDGS fed to pigs. Effects of individual or combined phytase (0 or 250 units/kg of feed), xylanase (0 or 4,000 units/kg of feed) on nutrient digestibility were investigated together with a particle size reduction treatment in diets containing wheat DDGS or an N-free diet in a 6 x 6 Latin square. Diets were formulated to contain 3.75 Mcal DE/kg and 0.37% chromic oxide. Each of 6 cannulated pigs (37.1 ± 0.75 kg of BW) was fed 6 diets at 2.8 x maintenance for DE in successive 9-d periods for 6 observations per diet. Feces and ileal digesta were collected subsequently for 2 d. Apparent total tract digestibility (ATTD) of energy was 1.0%-units higher (P = 0.009) for the ground than unground wheat DDGS. The DE content was 0.04 Mcal/kg DM higher (P =0.025) for ground DDGS than unground DDGS. Grinding of DDGS did not affect the ATTD of P. Phytase increased (P < 0.001) the DE content and the ATTD of P in the diet while xylanase decrease the DE content and P digestibility. Grinding improved (P < 0.003) the AID and SID of CP by 3.5 and 3.0%-unit respectively. Grinding of DDGS increased (P<0.003) the AID of most AA including Lys, Thr, and Met by 8.4, 1.5, and 2.6%-unit and increased (P<0.021) the SID for most of AA including Lys and Met by 7.4 and 1.5%-unit, respectively. Grinding increased (P<0.003) the SID content of Lys by 7.9%-unit. Individual supplementation of phytase did not affect the AID, SID or SID content of CP or AA, but xylanase show a reduction on these variables. A phytase x xylanase interaction did not occur. In summary, grinding wheat DDGS improved energy and AA digestibility as well as DE and SID AA content. Phytase and xylanase did not improve energy digestibility and not improved digestibility of AA. The combined results

indicate that the substrate for xylanase limit nutrient digestibility whereas phytate limited nutrient digestibility in wheat DDGS. Grinding is another possibility to enhance the nutritional value of wheat DDGS.

Introduction

Distillers dried grain with solubles (DDGS) is a co-product from the ethanol industry (Stein et al., 2006). The DDGS can be obtained from fermentation of different feedstocks such as corn, sorghum, barley, and wheat (Stein et al., 2006). The expansion of the ethanol industry also increased the mass of produced DDGS (Renewable Fuels Association, 2006). The recent increase in feedstuff prices indicates that DDGS has become an attractive feedstuff for the formulation of swine feeds (Lumpkins et al., 2004). After the fermentation process, the co-product wheat DDGS contains more of the anti-nutritional factors arabinoxylan than the feedstock wheat (Souffrant, 2001; Widyaratne and Zijlstra 2007), whereas the phytate in DDGS has been partially hydrolyzed (Widyaratne and Zijlstra 2007). These anti-nutritional factors reduce the nutritional value of energy, AA, and P in wheat DDGS.

The porcine digestive system does not secrete the enzymes xylanase and phytase to hydrolyze arabinoxylans and phytate, respectively (Golovan et al., 2001; Pointillart et al., 1984). At present, both xylanase and phytase are commercially available and may be included in the diets to enhance energy content of feeds or to reduce the supplementation or inorganic sources of phosphorous, respectively. Xylanase supplementation has been tested in poultry (Bedford, 2000) and swine (Mavromichalis, 2000), feeding wheat-based diets, but consistent positive effects were only observed in poultry. The inclusion of feedstocks with high NSP content like millrun in swine diets can decrease digestibility of energy, AA and P, but xylanase and phytase can partially ameliorate this effect (Nortey et al., 2007). Phytase

supplementation to swine diets consistently improves P digestibility, but not AA digestibility (Mroz et al., 1994). After fermentation to DDGS, the microbial fermentation makes more nutrients available to the pig or its hindgut bacteria; fibre soluble and P from phytate, the utilization of this fibre soluble and P can further enhance whit supplementation of both xylanase and phytase in swine diets. Finally, reducing the particle size of feedstuffs may increase nutrient digestibility in swine (Lawrence, 1967; Ivan et al., 1974), because contact surface area with enzymes in the stomach and intestinal lumen is increased, but the impact of grinding on nutrient digestibility of wheat DDGS is unknown.

New sources of wheat DDGS have become available, and the use of less heat to dry the DDGS in a new ethanol plant in western Canada may produce a wheat DDGS with better quality and an opportunity to improve nutrient digestibility with xylanase and phytase supplementation. The objectives of the present study were: 1) to measure the energy, AA, and P digestibility in grower pigs for diets containing wheat DDGS and establish the nutrient content for a new source of wheat DDGS, 2) to determine improvements in energy, AA and P digestibility with supplemental phytase and xylanase, and 3) to measure the effect of grinding on nutrient digestibility of wheat DDGS.

Materials and Methods

Experimental Design and Diets

Effects of phytase (0 or 250 units/kg of feed) and xylanase (0 or 4,000 units/kg of feed) were tested in a 2 x 2 factorial arrangement in 4 diets containing ground wheat DDGS, together with a diet containing unground wheat DDGS and a N-free diet, for a total of 6 diets in a fractional factorial arrangement. The 6 diets were fed to 6 pigs in a 6 x 6 Latin square. The phytase was 6-phytase (EC 3.3.26; Phyzyme XP; Danisco Animal Nutrition,

Marlborough, UK) and the xylanase was endo-1, 4-β-xylanase (EC 3.2.1.8; Porzyme 9300; Danisco Animal Nutrition). One FTU is defined as the quantity of phytase that liberates 1μM of ortho-phosphate per min from 5.1 mM Na-phytate at pH 5.5 and at 37°C (Engelen et al., 2001). The wheat DDGS used for this study was obtained from an ethanol plant (Husky, Lloydminster, Saskatchewan, Canada). The wheat DDGS was ground in a hammer mill through a 3/64"-screen prior to incorporation into the mash diets.

The wheat DDGS was the sole source of CP and AA in the 5 diets containing wheat DDGS. Diets contained also contained cornstarch, sucrose, canola oil, minerals and vitamins. Phytase and xylanase were included at 100 g/metric ton of finished feed. The N-free diet contained the feedstuffs cornstarch, canola oil, and sucrose as unique sources of energy; quantities were 57% higher for each of these feedstuffs than in the wheat DDGS-diets. The diets were fortified to meet vitamins and minerals requirements (NRC, 1998), except for being marginally limiting in P. Chromic oxide (0.37%) and Celite (1%) were included in the diets as indigestible markers.

Experimental Procedures

The animal protocol for the study was approved by the University of Alberta Faculty Animal Policy and Welfare Committee and followed established principles (CCAC, 1993). The experiment was conducted at the Swine Research and Technology Centre at the University of Alberta (Edmonton, Alberta, Canada).

Six crossbred barrows (Duroc sire x Large White/Landrace F1; Genex Hybrid; Hypor, Regina, Saskatchewan, Canada; initial BW, 37.1 ± 0.75 kg) were housed in raised individual metabolism pens that allowed freedom of movement (1.2 m wide, 1.2 m long, 0.9 m high). The pens were equipped with stainless steel self-feeder attached to the front of the pen, cup drinker

next to the feeder, plastic walls, and slatted flooring in a temperature-controlled room (22 ± 2.5°C). During a 10-d adaptation to the pens, barrows had free access to an 18%-CP pre-grower diet. Pigs were then fitted with a simple T-cannula at the distal ileum, approximately 5 cm prior to the ileocecal sphincter. The preparation of the cannulas, surgical procedure, and modifications were described previously (Sauer et al., 1983; De Lange et al., 1989). The pre- and post-operative care was described previously (Li et al., 1993). After surgery, barrows recovered for 7 d with a gradual increase in feed allowance. Pigs were fed 6 diets according to a 6 x 6 Latin square. Daily feed allowance was adjusted to 2.8 times the maintenance requirement for ME (3 x 110 kcal of DE/kg of $BW^{0.75}$; NRC, 1998), which was fed in 2 equal meals 0800 and 1500. The 9-d experimental period consisted of a 5-d acclimation to the experimental diets, followed by a 2-d collection of feces and a 2-d collection of ileal digesta. Pigs had free access to water throughout the experiment.

Feces were collected using plastic bags attached to the skin around the anus (Van Kleef et al., 1994). Digesta samples were collected for 2 d using soft plastic tubes (length, 20 cm; i.d., 4 cm) from 0800 to 2000 containing 15 mL of 5% formic acid was attached to the opened barrel of the cannula with a rubber band. Tubes were replaced as soon as filled or after 20 min (Li et al., 1993). Collected feces and digesta were pooled for each pig within experimental period and frozen at -20°C. Prior to analyses, feces and digesta were thawed, homogenized, sub-sampled, and freeze-dried.

Chemical Analyses

Feed and freeze-dried feces and digesta were ground finely in a centrifugal mill (model ZM 200; Retsch Co., Newtown, Pennsylvania) over 0.1- and 0.5-mm sieves, respectively. Feed, feces, and digesta were analyzed for moisture (method 930.15; Association of Official

Analytical Chemists (AOAC, 1990), ash (method 942.05; AOAC, 1990), ADF (method 973.18; AOAC, 1990), NDF (Van Soest et al., 1991), CF (method 962.09; AOAC, 1990), and ether extract (method 920.39; AOAC, 1990). Feed, feces, and digesta were analyzed for CP (method 990.03; AOAC, 1990) and the minerals P, Ca, K, Mg, and Na (method 985.01; AOAC, 1990). These analyses were conducted by Norwest Labs (Lethbridge, Alberta, Canada). The GE of feed, feces, and digesta was analyzed by an adiabatic calorimeter (model AC-300, Leco Corp., St. Joseph, MI). Chromic oxide of feed, feces, and digesta was analyzed by spectrophotometry after ashing at 450 nm (Fenton and Fenton, 1979). Acid-insoluble ash was analyzed in feed, feces, and digesta (McCarthy et al. 1974). Dietary starch was analyzed using the amyloglucosidase/α-amylase method with a final glucose analysis using a spectrophotometer at 510 nm (method 996.11; AOAC, 1990). The AA analysis was performed by HPLC (Turnell and Cooper, 1982) in a laboratory of the University of Missouri (Experiment Station, Chemical Laboratories). The analyses of diets were carried out in triplicate and analyses of feces and digesta in duplicate.

Calculations

The apparent ileal digestibility (AID) of DM, energy, Ca, and P were calculated by using the following equation (Adeola, 2001):

AID, % = 100 – [100 x (concentration of Cr_2O_3 in feed x concentration of component in feces or digesta / concentration of Cr_2O_3 in feces or digesta x concentration of component in feed)]

The apparent total tract digestibility (ATTD) of DM, energy, Ca, and P was also calculated using this equation).

The basal ileal endogenous loss (I_{end}) of an AA or CP (g/kg of DM intake) was calculated by the equation for the N free diet (Stein et al., 2007):

I_{end} = [AA or CP in digesta x (Cr_2O_3 in feed / Cr_2O_3 in digesta)]

The standardized ileal digestibility (SID) values for each indispensable amino acid were then calculated by the equation (Stein et al., 2007):

SID = [AID + (IAA_{end} /AA in feed)]

The DE in the DDGS samples was calculated by subtracting the specific amount of DE in the N-free diet provided by the energy-providing feedstuffs from the DE in each of the DDGS containing diets according to the difference method (Adeola, 2001):

Digestibility of the component in the test article, A, % = 100 x [(T x Tp)-(B x Bp) / Ap]

Where: T is the digestibility, %, of the component in the total diet (basal plus test article); B is the digestibility, %, of the component in the basal diet; Bp is the proportion, %, of the component in the total diet contributed by the basal diet, Ap is the proportion, %, of the component in the total diet contributed by the test article, and Tp = Bp + Ap = 100%. The content of SID CP and AA was calculated by multiplying SID digestibility measured in the digesta sample x total CP and AA content of wheat DDGS.

Statistical Analyses

The N-free diet was solely used for calculations and was excluded from statistical analyses. The data were analyzed as a 5 x 5 Latin square model, using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC). The main effects (phytase and xylanase) of the ground wheat

DDGS were analyzed using diet, period, and pig in the model. In addition, in case a significant interaction between main effects was observed, the 4 treatments were separated using the probability of difference. Unground DDGS and the ground control DDGS were compared using a preplanned contrast statement. Individual pig was considered the experimental unit. Differences were considered significant if $P < 0.05$.

Results

Pigs remained healthy during the experimental period. One pig was removed from the study, because the cannula was not functioning properly. Orts were not collected; pigs consumed their daily feed allowance throughout the experiment, regardless of the offered diet.

The GE content of the wheat DDGS was 4.70 Mcal/kg (Table 2). Wheat DDGS contained 7.99 % ether extract, 7.14% crude fiber, 39.75% NDF, 30.96 CP %, and 0.85% P. Wheat DDGS contained 1.04% Lys.

The chemical and AA composition of the experimental diets is presented in Table 3. The differences in analyzed values among the experimental diets were small. The calculations and statistical analyses were based on analyzed values.

The ATTD of GE was 1.5%-unit higher ($P < 0.001$) for the ground control DDGS diet than the unground diet (Table 4). The resulting ATTD of GE was 3.8%-units higher ($P = 0.05$) for the ground than unground DDGS. The DE content of the ground DDGS was 0.04 Mcal/kg of DM higher ($P < 0.001$) for ground than unground DDGS and 0.06 Mcal/kg of DM higher ($P = 0.009$) in the diet containing unground than ground DDGS. Grinding of DDGS did not affect the ATTD of P in the diets.

Xylanase and phytase did not affect the ATTD of GE in the diets or DDGS and did not affect the DE content of the DDGS (Table 4). Phytase and xylanase interacted ($P < 0.05$) for

the DE content of the wheat DDGS. Phytase increased ($P < 0.001$) the DE content 0.07 Mcal/kg of DM in the whole diet. Phytase increased ($P < 0.001$) the ATTD of P in the diet by 21.9%-units. Xylanase did not affect the ATTD of P. A xylanase x phytase interaction did not occur.

The AID of CP was 2.4%-unit higher ($P < 0.001$) in the diet containing ground DDGS compared to unground DDGS (Table 5). The AID for most of the indispensable and dispensable AA was higher ($P < 0.002$) for the ground than unground DDGS diet. The increase ($P < 0.003$) was 6.5, 2.6, and 1.2%-unit in AID for Lys, Thr, and Met, respectively. Phytase supplementation did not affect the AID of indispensable or dispensable AA. Xylanase supplementation reduced the AID of some AA; Lys was reduced by 2.6, Thr by 1.8, and Met by 0.5%-unit. A phytase x xylanase interaction did not occur.

The SID of CP was 2.1%-unit higher ($P = 0.022$; Table 6) in the diet containing ground DDGS compared to unground DDGS. The SID for most of the indispensable and dispensable AA was higher ($P < 0.039$) for the ground than unground DDGS diet. The increase ($P < 0.05$) was 9.2, 2.0 and 1.1%-unit in SID for the Lys, Thr and Met, respectively. Phytase supplementation did not affect the SID of indispensable or dispensable AA. A phytase x xylanase interaction did not occur.

The SID content of CP was 2.1%-unit higher ($P = 0.006$; Table 7) in the diet containing ground DDGS compared to ground DDGS. The SID content of indispensable and dispensable AA (with the exception of Met, Trp, Val, and Pro) was higher ($P < 0.041$) for the ground than unground DDGS diet. Specifically, the increase in SID content was in 5.8%-unit for Lys and 1.2%-unit for Thr. Individual supplementation of phytase or xylanase did not affect the SID content of CP or AA and a phytase x xylanase interaction did not occur.

Discussion

In the present study, energy, AA and P digestibility of a wheat DDGS-based diet was measured in ileal-cannulated grower pigs. Supplemental phytase and xylanase in wheat DDGS-based diets did not improve energy and AA nutrient digestibility, but phytase improved P digestibility. Grinding wheat DDGS increased nutrient digestibility.

Wheat DDGS

In the present study, the chemical and nutritional profile of the wheat DDGS indicate that this co-product is a source of digestible energy and AA (Table 2). The nutrient profile of wheat DDGS is different than wheat, because starch is removed during fermentation (Mustafa et al., 1999). The content of P and CP is higher, and as a consequence, the values for all AA are higher than the AA profile of the feedstock used in the process, in this case wheat grain (Nyachoti et al., 2005; Widyaratne and Zijlstra, 2007). The sample of wheat DDGS used in the present study was different compared with the sample of wheat DDGS used by Widyaratne and Zijlstra (2007). The wheat DDGS was 13.54%-units lower in CP content, thereby explaining the lower AA content. Ether extract was 5.09%-units higher and crude fiber was 0.46%-units lower. Similarly, Nyachoti et al. (2005) used a DDGS sample based on winter wheat that was 1.12 and 23.32%-units higher in energy (Mcal/kg) and CP, respectively. The content of most AA is similar, except Lys, which was 53.85%-unit less, indicating a very low protein quality of the sample used by Nyachoti et al. (2005). The P content was the same in the sample used in the present study. The variation in nutrient content among samples of wheat DDGS is due type and quality of cereal used, fermentation method, duration of the process, duration and drying temperature and the amount of solubles used in the process (Carpenter et al., 1970; Olentine et al., 1986; Spiehs et al., 1998).

One of the main observations in this study is the Lys content of the wheat DDGS, which is the only AA with a higher content compared with the AA content of wheat DDGS in a previous study (Widyaratne and Zijlstra, 2007). The higher Lys content coincided with a more yellow than brown color and a more acceptable odor in the wheat sample used in the present study.

Phytase and Xylanase Supplementation

The supplementation of phytase, xylanase or combination of both enzymes did not improve the ATTD of GE in the whole diets or in the DDGS and the DE content in the DDGS, as in previous studies the effect of combining phytase and xylanase in wheat-based diets are inconsistent. For example, Selle et al. (2003) reported synergism between the 2 enzymes in broilers fed wheat-based diets on ADG, G:F, and AA digestibility. The response was contributed to complementary modes of action for enhancing nutrient digestibility and facilitating substrate access. Nortey et al. (2007) reported that individually or combined supplementation of xylanase and phytase improved DE content in diets containing 20 or 40% millrun. Olukosi et al. (2007) reported that only the combination of xylanase and phytase improved the DE and daily retention of energy in diets including wheat middlings. Kim et al. (2005) reported that a supplemental phytase and xylanase decreased the ATTD of energy in pigs were fed a wheat-basis diet. A change in digestibility of nutrients in diets supplemented with phytase and xylanase can be explained by suggested modes of action. Zyla et al. (1999) reported increase intestinal viscosity by supplementation of phytase in wheat-based diet fed to chicks. Simon and Igbasan (2002) mentioned different pH ranges of maximum activity for phytase and xylanase. This mismatch may not permit a synergism sequence supplementing

xylanase plus phytase breakdown the NSP structure by xylanase and the subsequent action of phytase on released phytic acid to release free components.

Although the quantity of fiber is higher in wheat DDGS than in wheat grain, this fiber did not respond to supplemental xylanase. Yin et al (2000) mentioned that an increased level of fiber content is associated with decreased available energy content in pigs. The addition of xylanase may improve nutrient availability through disruption or solubilization of cell wall polysaccharides, resulting in reduction or elimination of the encapsulating effects of the cell wall Dierick and Decuypere (1994). However Knudsen and Hansen (1991) indicated that the influence of feed enzyme addition on nutrient digestibility is dependent on the substrate available to the exogenous enzyme. Perhaps the wheat arabinoxylans were altered in composition during fermentation and drying so that the supplemented xylanase could not hydrolyze the arabinoxylans.

Digestible nutrient information is important for diet formulation, as DDGS is a co-product the DE content remained lower in the original feedstock than in the wheat DDGS this in agreement with Widyaratne and Zijlstra (2007) but contrasting with previous research conducted by Nyachoti et al (2005) who indicate that feedstock had a higher DE content than wheat DDGS. The DE content in the whole diet was improved with phytase supplementation this results are in agreement with results reported by Johnston et al. (2004) who used phytase supplementation in wheat-based diets. The ATTD of P not was improved by xylanase supplementation contrasting with the report of Nortey et al. (2007) who report an increase in the ATTD of P feeding millrun diets.

In contrast, phytase supplementation improved ATTD of P. The effectiveness of phytase to hydrolyze phytate in pigs has been well documented (e.g., Simons et al., 1990; Lei et al., 1993; Mroz et al., 1994).) The ATTD of P was higher in the DDGS than in the feedstock wheat (Widyaratne and Zijlstra 2007). The fermentation process itself increased mineral

availability. The concentration of total P is two or three times higher in wheat DDGS than in the parent grain stock; however, in the fermentation process, phytate is partially hydrolyzed caused by overheating and drying process (Batal, 2006). Still, the residual phytate P could cause negative impact on P digestibility and increase excretion contributing at environmental pollution, so the action of phytase can be focus in the phytate (IP6) fraction and not in the other inositol phosphates forms (e.g., IP5, IP4, IP3, IP2). Wheat DDGS may therefore be an ingredient to consider in feed formulation to reduce P excretion in pig manure.

The phytase supplementation is not consistent in improving AID and SID. Some experiments show improvements. Mroz et al. (1994) reported an increase in the AID of AA (except for cystine and proline) in pigs feeding with a corn-tapioca-soybean meal diet. Similarly, Nortey et al. (2007) reported improvements in the AID Lys, Thr, Val, Leu and Ile in diets including wheat millrun supplemented with phytase. In the present study, the AID and SID did not was improved in agreement with reports by Bruce and Sundstol (1995) feeding an oats-based diet in pigs, Traylor et al. (2001) feeding a diet containing dehulled soybean meal, and Liao et al. (2005) feeding growing pigs with different diets (corn-soybean; wheat-soybean meal; wheat-soybean meal-canola meal; barley-peas-canola meal).

The AID and SID was partially improved in indispensable AA (Lys, Met, Phe, Thr and Val) and dispensable AA (Asp, Cys, Glu, Ser and Tyr) by xylanase supplementation in the current study. These results are in agreement with a report by Barrera et al. (2004) indicating that xylanase increased AA digestibility in growing pigs fed a wheat-based diet. Although co-products from wheat as wheat DDGS contain high levels of non-starch polysaccharides (NSP) that reduce its nutritive value (Souffrant, 2001), the pigs do not secrete the enzymes to hydrolyze this compounds which are substrate for xylanase.

Grinding

The ATTD of GE and DE content was higher in ground control diet and ground DDGS than unground diet and unground DDGS. Grinding will reduce particle size and thereby nutrient digestibility by increasing the relative surface area of dietary particles exposed to enzymatic digestion in the gastrointestinal tract and increasing digestion and absorption of nutrients (Goodband et al., 1996). Reducing particle size may also reduce the excretion of N by decreasing AA losses. Oryschak et al. (2002) mentioned that a synergism does not exist between particle size reduction and supplemental dietary enzymes to increase nutrient digestibility. Even though surface area is increased by grinding, the supplemented enzymes do hydrolyze remaining anti-nutritional factors and enzyme cocktails might be required to show an improvement in nutrient digestibility. The results in the present study are similar to reports that demonstrated improved energy digestibility with smaller particle size of sorghum and corn (Healy et al., 1994; Cabrera et al., 1994, Wondra et al. 1995a,b,c,d). However, the results in this experiment are in contrast with results reported by Ivan et al. (1974), who reported that fineness of grind in wheat-based diets had little effect on nutrient digestibility. The combination of fine grinding and xylanase supplementation did improve nutrient digestibility in wheat-based diets (Mavromichalis et al., 2000).

The AID and SID of AA with exception of Trp and Pro was improved by grinding in wheat DDGS, as reported in previous study by Fastinger and Mahan (2003) and Owsley et al. (1981). The AID and SID was increased while particle size was reduced increasing the digestibility of some AA in grower pigs, particularly in indispensable AA. In other experiments particle size reduction improved CP digestibility (Wondra et al., 2005a,b,c,d), indicating that AA digestibility was improved.

In conclusion, wheat DDGS has a potential to replace energy and protein-yielding feedstuffs for grower pigs. The inclusion of wheat DDGS must be careful due variation

between ethanol plants procedure and incorrect AA balance can be expected. Phytase and xylanase did not improve the nutrient digestibility in diets containing wheat DDGS, only phytase supplementation improve P digestibility. Grinding improved the nutrient digestibility in wheat DDGS with exception in P indicating that feed processing should be part of a package to enhance the nutritional value of wheat DDGS.

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Table 1. Ingredient composition (as-fed basis) of the experimental diets

	Wheat DDGS[1]					
	Ground				Unground	
Ingredient, %	CON	PHY	XYL	PHY+XYL	CON	N-free
Cornstarch	48.27	48.44	48.17	48.34	48.28	85.25
Wheat DDGS, ground[2]	43.70	43.70	43.70	43.70	-	-
Wheat DDGS, unground[3]	-	-	-	-	43.70	-
Phytase[4]	-	0.10	-	0.10	-	-
Xylanase [5]	-	-	0.10	0.10	-	-
Sugar	3.00	3.00	3.00	3.00	3.00	5.25
Solka floc	-	-	-	-	-	3.00
Canola oil	1.00	1.00	1.00	1.00	1.00	1.75
Limestone	1.15	0.88	1.15	0.88	1.15	0.16
Dicalcium phosphate	-	-	-	-	-	1.13
Salt	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin premix[6]	0.50	0.50	0.50	0.50	0.50	0.50
Mineral premix[7]	0.50	0.50	0.50	0.50	0.50	0.50
KCO_3	-	-	-	-	-	0.50
M_gO	-	-	-	-	-	0.10
Acid insoluble ash	1.00	1.00	1.00	1.00	1.00	1.00

Chromic oxide	0.37	0.37	0.37	0.37	0.37	0.37

[1]CON = control; XYL = xylanase; PHY = phytase.

[2]Wheat DDGS with the following composition: DM, 88.39 %, GE, 4710.5 kcal, CP, 33.4 %, crude fiber, 7.1 %, NDF, 30.0 %, ADF, 16.2 %, ether extract, 7.03%, P, 0.86 %, Ca, 0.12 %. Wheat DDGS was ground through 3/4"-screen.

[3]Wheat DDGS was not ground.

[4]Phytase was included at 100 g/1,000 kg of feed to provide 250 FTU/kg of feed.

[5]Xylanase was included at 167 g/1,000 kg of feed to provide 4,000 U/kg of feed.

[6]Provided the following per kilogram of diet: vitamin A, 8,250 IU; vitamin D_3, 825 IU; vitamin E, 40 IU; niacin, 35 mg; D-pantotenic acid, 15 mg; riboflavin, 5 mg; menadiona, 4 mg; folic acid, 2 mg; thiamine, 1 mg; D-biotin 0.2 mg; and vitamin B_{12}, 0.025 mg.

[7]Provided the following per kilogram of diet: Zn, 100 mg as $ZnSO_4$; Fe, 80 mg as $FeSO_4$; Cu, 50 mg as $CuSO_4$; Mn, 25 mg as manganous sulfate; I, 0.5 mg as Ca iodate; and Se, 0.1 mg as Na_2SeO_3.

Table 2. Analyzed nutrient composition (as-fed basis) of the wheat DDGS[1]

Item	Wheat DDGS
Moisture, %	8.63
CP, %	30.96
GE, Mcal/kg	4.71
Ether extract, %	7.99
Ash, %	4.93
ADF, %	11.12
NDF, %	39.75
Crude fiber, %	7.14
Starch, %	1.95
P, %	0.85
Ca, %	0.11
Indispensable AA, %	
Arg	1.53
His	0.79
Ile	1.31
Leu	2.76
Lys	1.04
Met	0.54
Phe	1.86
Thr	1.15

Trp	0.27
Val	1.50
Dispensable AA, %	
Ala	1.53
Asp	1.80
Cys	0.64
Glu	6.61
Gly	1.34
Pro	2.56
Ser	1.37
Tyr	1.39

Table 3. Analyzed nutrient composition (as-fed basis) of the experimental diets[1]

	Wheat DDGS					
	Ground				Unground	
Item	CON	PHY	XYL	PHY+XYL	CON	N-free
DM, %	91.3	91.5	91.6	91.6	91.3	93.7
CP, %	16.22	16.18	15.29	15.40	15.20	0.64
GE, Mcal/kg	4.12	4.13	4.13	4.14	4.09	3.87
Ether extract, %	3.84	4.02	3.98	3.94	3.53	1.83
ADF, %	8.20	7.40	6.30	6.50	8.40	1.90
NDF, %	13.00	12.70	12.60	12.80	14.40	5.40
Crude fiber, %	3.20	3.30	3.20	3.50	3.40	1.30
Starch, %	41.40	41.32	40.89	41.35	41.00	74.83
P, %	0.39	0.39	0.38	0.40	0.40	0.21
Ca, %	0.67	0.56	0.69	0.59	0.68	0.33
Indispensable AA, %						
Arg	0.77	0.77	0.73	0.74	0.72	0.01
His	0.38	0.38	0.37	0.37	0.36	0.00
Ile	0.82	0.79	0.78	0.80	0.77	0.19
Leu	1.22	1.25	1.20	1.19	1.13	0.04
Lys	0.52	0.52	0.49	0.49	0.48	0.02
Met	0.26	0.26	0.26	0.25	0.25	0.01
Phe	0.80	0.80	0.76	0.76	0.74	0.02

Thr	0.53	0.54	0.51	0.51	0.50	0.01
Trp	0.18	0.18	0.18	0.17	0.19	0.04
Val	0.80	0.80	0.76	0.77	0.75	0.00
Dispensable AA, %						
Ala	0.70	0 72	0.69	0.68	0.65	0.02
Asp	0.90	0.91	0.87	0.86	0.84	0.02
Cys	0.32	0.33	0.30	0.30	0.29	0.02
Glu	4.39	4.30	4.04	4.12	4.15	0.15
Gly	0.73	0.72	0.68	0.68	0.68	0.01
Pro	1.52	1.52	1.40	1.43	1.45	0.00
Ser	0.70	0.71	0.66	0.66	0.66	0.02
Tyr	0.50	0.51	0.48	0.48	0.46	0.01

[1]CON = control; XYL = xylanase; PHY = phytase.

Table 4. Apparent total tract digestibility (ATTD) of energy, and the concentration of DE in wheat DDDGS supplemented with phytase and xylanase.

	Wheat DDGS									
	Ground				Unground	Pooled	*P*-values[1]			
Item	CON	PHY	XYL	PHY+XYL	CON	SEM	PHY	XYL	PHY×XYL	Grinding
ATTD of GE, %										
Diet	84.92	84.68	84.33	84.91	84.06	0.11	0.428	0.401	0.067	0.009
DDGS	70.74	70.20	69.40	70.72	68.78	0.52	0.750	0.735	0.448	0.265
DE, Mcal/kg of DM										
Diet	3.72	3.80	3.68	3.77	3.75	0.01	<0.001	0.043	0.639	0.260
DDGS	3.71	3.70	3.68	3.71	3.67	0.01	0.130	0.321	0.064	0.025
ATTD of P, %										
Diet	50.91	63.29	42.21	61.55	52.82	1.81	<0.001	0.032	0.140	0.557

[a-c]Means within in the same row with the same superscript letters are not different ($P > 0.05$). Means are based on 5 observations per treatment.

[1]*P*-values obtained from comparison in principal effects PHY= phytase, XYL= xylanase and their interaction PHY+XYL. An pre-planned contrast was included to compare digestibility values of ground versus unground DDGS.

Table 5. Apparent ileal digestibility (%) of CP and AA in diets containing wheat DDGS[1]

	Wheat DDGS									
	Ground				Unground	Pooled	*P*-values[2]			
Item, %	CON	PHY	XYL	PHY+XYL	CON	SEM	PHY	XYL	PHY+XYL	Grinding
CP	89.6	88.5	87.6	88.4	86.5	0.280	0.791	0.037	0.060	<0.001
Indispensable AA										
Arg	91.1	90.1	89.3	90.3	87.8	0.306	0.975	0.124	0.072	<0.001
His	89.0	88.2	87.4	88.2	87.0	0.190	0.975	0.020	0.018	<0.001
Ile	90.6	89.8	89.1	90.0	89.4	0.166	0.871	0.072	0.013	0.015
Leu	91.2	90.8	90.0	90.6	89.7	0.149	0.689	0.010	0.050	<0.001
Lys	79.5	77.9	75.2	76.2	72.8	0.644	0.805	0.015	0.245	<0.001
Met	90.7	90.4	89.5	89.5	89.3	0.171	0.612	0.002	0.501	0.003
Phe	92.4	91.8	91.1	91.7	91.0	0.139	0.936	0.003	0.014	<0.001
Thr	83.5	82.9	80.8	81.9	81.3	0.269	0.633	<0.001	0.066	<0.001

Trp	91.8	91.7	91.3	91.0	91.3	0.129	0.389	0.040	0.745	0.231
Val	88.6	87.6	86.5	87.4	87.1	0.226	0.980	0.013	0.043	0.024
Dispensable AA										
Ala	85.9	85.3	84.0	84.8	82.7	0.291	0.897	0.016	0.160	<0.001
Asp	78.7	78.0	76.2	77.0	74.9	0.343	0.908	0.002	0.139	<0.001
Cys	86.4	86.4	85.4	85.8	85.5	0.158	0.527	0.027	0.496	0.066
Glu	94.3	94.0	93.5	93.9	93.4	0.089	0.934	0.004	0.018	<0.001
Gly	83.3	80.7	80.1	81.2	77.0	0.602	0.487	0.211	0.106	<0.001
Pro	91.0	86.7	86.3	88.5	79.2	1.455	0.733	0.624	0.294	0.011
Ser	87.0	86.6	85.0	85.9	85.0	0.226	0.637	0.001	0.125	0.001
Tyr	91.4	90.9	89.7	90.2	89.6	0.171	0.961	<0.001	0.060	<0.001

[1]Values are mean for 9 observations per treatment.

[2]P-values obtained from comparison in principal effects PHY= phytase, XYL= xylanase and their interaction PHY+XYL. A preplanned contrast was included to compare digestibility values of ground versus unground DDGS.

[3]*P*-values obtained from comparison in principal effects PHY= phytase, XYL= xylanase and their interaction PHY+XYL. An pre-planned contrast was included to compare digestibility values of ground versus unground DDGS.

Table 6. Standardized ileal digestibility (%) of CP and AA in diets containing wheat DDGS[1,2]

	Wheat DDGS									
	Ground				Unground	Pooled	*P*-values[3]			
Item, %	CON	PHY	XYL	PHY+XYL	CON	SEM	PHY	XYL	PHY+XYL	Grinding
CP	93.1	92.0	91.3	91.3	90.3	0.270	0.263	0.015	0.308	<0.001
Indispensable AA										
Arg	94.7	93.8	93.2	93.1	91.7	0.276	0.263	0.025	0.408	<0.001
His	91.6	90.8	90.1	90.1	89.8	0.228	0.408	0.029	0.359	<0.001
Ile	93.0	92.3	91.7	92.0	92.0	0.206	0.609	0.074	0.269	0.110
Leu	93.4	93.0	92.3	92.2	92.1	0.203	0.579	0.038	0.601	0.037
Lys	84.2	82.6	80.3	79.8	78.0	0.682	0.415	0.015	0.677	0.002
Met	92.2	91.9	91.0	90.8	90.8	0.205	0.504	0.009	0.825	0.021
Phe	94.4	93.8	93.2	93.2	93.2	0.183	0.473	0.027	0.445	0.031
Thr	88.6	87.9	86.2	86.0	86.7	0.388	0.576	0.014	0.743	0.109

Trp	95.1	95.0	94.6	93.7	94.6	0.256	0.356	0.134	0.500	0.551
Val	91.3	90.4	89.3	89.5	90.0	0.269	0.516	0.023	0.345	0.118
Dispensable AA										
Ala	89.6	88.9	87.8	87.8	86.7	0.310	0.566	0.018	0.507	<0.001
Asp	82.9	82.2	80.5	80.3	79.4	0.414	0.549	0.014	0.732	0.005
Cys	89.4	89.2	88.5	88.2	88.7	0.254	0.716	0.106	0.862	0.418
Glu	95.4	95.1	94.7	94.7	94.6	0.110	0.499	0.027	0.371	0.013
Gly	91.4	89.0	88.8	88.5	85.7	0.566	0.221	0.163	0.314	<0.001
Pro	98.4	97.4	97.6	97.2	90.2	1.422	0.446	0.544	0.527	0.150
Ser	90.5	90.1	88.7	88.8	88.7	0.281	0.711	0.012	0.657	0.030
Tyr	93.7	93.2	92.2	90.1	92.1	0.227	0.469	0.007	0.671	0.021

[1]Treatment means are based on 9 observations per treatment.

[2]Standardized ileal digestibility was calculated by correcting the apparent ileal digestibility for the basal ileal endogenous losses (Stein et al, 2007).

[3]*P*-values obtained from comparison in principal effects PHY= phytase, XYL= xylanase and their interaction PHY+XYL. An pre-planned contrast was included to compare digestibility values of ground versus unground DDGS.

Table 7. Content of standardized ileal digestible CP and AA (%) in wheat DDGS[2]

	Wheat DDGS									
	Ground				Unground	Pooled	*P*-values[3]			
Item, %	CON	PHY	XYL	PHY+XYL	CON	SEM	PHY	XYL	PHY+XYL	Grinding
CP	28.81	28.49	28.27	28.26	27.95	0.084	0.266	0.015	0.307	<0.001
Indispensable AA										
Arg	1.45	1.43	1.43	1.42	1.40	0.004	0.205	0.041	0.475	<0.001
His	0.72	0.71	0.71	0.71	0.71	0.002	0.164	0.057	0.164	<0.001
Ile	1.22	1.21	1.20	1.20	1.20	0.003	0.372	0.028	0.216	0.031
Leu	2.58	2.57	2.54	2.55	2.54	0.006	0.683	0.037	0.568	0.047
Lys	0.88	0.86	0.84	0.83	0.81	0.007	0.455	0.017	0.653	0.003
Met	0.50	0.50	0.49	0.49	0.49	0.001	0.727	0.092	0.727	0.329
Phe	1.76	1.75	1.73	1.73	1.73	0.003	0.477	0.023	0.477	0.023
Thr	1.02	1.01	0.99	0.99	1.00	0.005	0.470	0.010	0.756	0.067
Trp	0.26	0.25	0.25	0.25	0.26	0.001	0.203	0.203	0.666	0.542

Val	1.37	1.36	1.34	1.34	1.35	0.004	0.645	0.030	0.361	0.152
Dispensable AA										
Ala	1.37	1.36	1.34	1.34	1.33	0.005	0.420	0.014	0.420	<0.001
Asp	1.49	1.48	1.45	1.44	1.43	0.007	0.534	0.012	0.835	0.006
Cys	0.57	0.57	0.57	0.56	0.57	0.001	0.576	0.104	0.576	0.431
Glu	6.31	6.28	6.26	6.26	6.25	0.007	0.406	0.026	0.334	0.009
Gly	1.23	1.19	1.19	1.19	1.15	0.008	0.120	0.158	0.375	0.001
Pro	2.60	2.49	2.50	2.49	2.31	0.036	0.456	0.554	0.520	0.015
Ser	1.24	1.23	1.22	1.22	1.22	0.004	0.618	0.020	0.618	0.044
Tyr	1.31	1.29	1.28	1.28	1.28	0.003	0.257	0.002	0.414	0.010

[1]Treatment means are based on 9 observations per treatment.

[2]Content of standardized ileal digestible CP and AA was calculated by multiplying SID digestibility measured in the digesta sample x total CP and AA content of wheat DDGS.

[3]*P*-values obtained from comparison in principal effects PHY= phytase, XYL= xylanase and their interaction PHY+XYL. An pre-planned contrast was included to compare digestibility values of ground versus unground DDGS.

Appendix 7. Variability of quality in biofuel co-products

Introduction

Fossil fuels are the main transportation energy source for human activity. However, the resulting release of 'greenhouse gases' has also been related to climate change (Grubb et al., 1999). Considerable demand thus exists to replace fossil fuels with renewable fuel sources such as biodiesel and ethanol, even though the debate continues as to whether or not this is a worthwhile exercise (e.g., Farrell et al., 2006). Biofuel production can be divided into two principal categories: (1) ethanol production and (2) biodiesel production.

Ethanol is currently produced at a commercial scale via the enzymatic breakdown of starch and yeast-driven fermentation of glucose into ethanol. Ethanol production based on cellulose is currently in the development phase. A number of grain starch sources can be used; however, maize is predominantly used globally with regional efforts in Canada and Europe geared towards using wheat or other small grains as a feedstock. Distillers' dried grain and solubles (DDGS) is the predominant co-product from ethanol production in North America, although wet feeding of the solubles or combined distiller's grain and solubles in also practiced.

Biodiesel is currently produced at a commercial scale via the conversion of oil extracted from oilseeds such as soybean and canola or rapeseed or animal fat. In large-scale extraction plants, the oil from oilseeds is usually extracted using hexane and a protein meal is the resulting co-product. In medium-and small scale plants, the oil can be extracted using an expeller or screw-press, respectively; expeller meal or press cake are then the resulting co-products, respectively. Subsequent transesterification of the extracted oil into biodiesel also produces crude glycerol as a co-product.

Co-products, by the fact that they have been processed, will be feedstuffs with more nutrient variability than the feedstock of origin. Apart from the inherent variability in feedstock composition, additional variability is introduced due to processing required to produce biofuels. A feedstock that has a limited compositional variability, such as hybrid maize, contrasts to massive variability in the DDGS co-product, due to processing, including milling, fermentation, drying, and removal or addition of specific fractions (Stein, 2007). Co-products should therefore be sourced from specific plants and not specific geographical regions to limit variability in feedstuff due to processing. Biofuels plants are not necessarily built to optimize co-product quality. Addressing co-product variability may therefore be an afterthought after commissioning and reaching top biofuel production.

The biofuel co-products

The production of biofuels and therefore co-products is quickly expanding. However, a few co-products such as DDGS, oilseed meal and cake, and glycerol are now common feedstuffs.

Distillers' Dried Grain and Solubles. The DDGS is a co-product from the cereal grain-based ethanol and alcohol beverage industries (Newland and Mahan, 1990). With the rapid growth of the ethanol industry, increasing quantities of DDGS are available for livestock feeding. Maize DDGS is largely produced in the USA and eastern Canada whereas wheat DDGS is produced in Europe and western Canada. In general, DDGS has higher concentration of nutrients such as protein, fat, vitamins, minerals, and fibre than its parent grain stock. These nutrients concentrate due to a conversion of most of the cereal starch to ethanol and carbon dioxide during the fermentation process (Weigel et al., 1997).

The process of production of ethanol and DDGS follows several typical steps (Patience et al. 2007) in most ethanol plants: dry milling of grain, fermentation, distillation of the ethanol, and drying of the distillers' grain. In the latter stage, the soluble components that have been separated before for distillation are blended back together with the distillers' grain containing most of the solids during the final drying. Recently, additional steps have been added to remove grain fractions prior to fermentation. Germ, oil and hulls (fibre) are sometimes removed upfront to first, target specific markets, and second, to enhance the efficiency of the fermentation process. Each single step or a combination of them, however, introduces more variability in the nutritional quality (profile and availability) of DDGS in the global market place.

Oilseed meal and cake. For the purpose of this chapter, the focus of oilseed meal and cake will be on canola. Variability of soybean meal quality has been described elsewhere (Van Kempen et al., 2002) and canola is likely the most important source of biodiesel in Europe. Canola meal is produced using solvent-extraction using hexane (Thacker, 1990). Therefore, canola meal has a low content of residual oil. Canola expeller meal is generated following heat conditioning of the seed and crushing in the expeller press operated to optimise oil extraction that may generate temperatures up to 135°C for the brief period that seed is passing through the press. Some plants operate double- or triple-pass systems where seed cake is reprocessed to increase oil recovery. Oil may also be extracted using a cold, screw press, where seed is not pre-conditioned prior to oil extraction, and temperatures up to 65°C are generated by the screw pressing against the chamber merely by frictional force. Therefore, canola expeller meal will have a higher residual oil content than solvent-extracted canola meal, with even higher residual oil content for cold-pressed cake (Leming and Lember, 2005; Spragg and Mailer, 2007). Cold pressing of canola does not require as high a capital investment, and might be a favourite for local extraction of oil for biodiesel production (Bender, 1999).

Crude glycerol. To produce biodiesel, the oil extracted from oilseeds undergoes transesterification using an alcohol and a catalyst, thereby producing methyl esters for biodiesel production and crude glycerol as a resulting co-product (Kerr et al., 2007). The production of one litre of biodiesel may yield 79 g of crude glycerol (Thompson and He, 2006). Glycerol forms the backbone of triglycerides and is involved in phospholipid synthesis in hepatic and adipose tissue (Mourot et al., 1994). In the small intestine of pigs, ingested fats are broken down into three compounds: two free fatty acids and a monoglyceride. Following absorption, these compounds are transported to the liver, and the monoglyceride is broken down into glycerol and a third free fatty acid. Dietary glycerol can then be converted to glucose via gluconeogenesis or oxidized as a

source of energy via glycolysis and the citric acid cycle. Thus, dietary glycerol may provide energy (Mourot et al., 1994; Lammers et al., 2008), be stored as glycogen, or be used to form body fat (lypogenesis). Processing methods used for the production of biodiesel may result in varying levels of impurities. Alcohol, salts and heavy metals can be found in crude glycerol (Doppenberg and Van der Aar 2007; Johnson and Taconi, 2007). Future use of crude glycerol in livestock feeds may be subject to feed regulations.

Variability of quality in DDGS

A major source of variation in the quality of DDGS is the botanical origin of the feedstock (Widyaratne and Zijlstra, 2007). Maize contains more starch and oil and less protein and fibre than wheat (CVB, 2006; Sauvant et al, 2004). Following starch conversion to ethanol and carbon dioxide during fermentation, the DDGS reflects the original feedstock in a concentrated form (approximately 3x). Co-fermentation, the combined fermentation of two or more feed stocks (maize and wheat), is currently common practice in western Canada (Table 1). Alterations in the ratio of co-fermented feedstocks will add to the variability in the quality of DDGS.

Table 1. Chemical characteristics of wheat, and maize, wheat/maize, and wheat distiller's dried grains with solubles (g/kg DM)[1]

		Distiller's dried grains with solubles		
Variable	Wheat	Maize	Wheat/maize[2]	Wheat
Moisture	118	118	80	81
Crude protein	198	303	424	445
Non-protein nitrogen	46	54	124	102
Crude fat	18	128	47	29
Ash	21	48	50	53
Acid detergent fibre	27	146	195	211
Neutral detergent fibre	94	312	306	303
Crude fibre	24	70	78	76
Amino acid				
Cysteine	4.8	7.0	8.9	9.6
Lysine	5.2	8.3	7.2	7.2
Methionine	3.2	6.1	6.7	6.9
Threonine	5.4	10.9	12.2	12.8
Tryptophan	2.3	2.3	3.7	4.4
Total	194.8	283.2	372.5	402.1

[1]Source: Widyaratne and Zijlstra (2007).

[2]Derived from the combined fermentation of wheat and maize in a 4:1 ratio.

Similar to other chemical characteristics, phosphorus is concentred in maize and wheat DDGS (Table 2). Intact phytate, i.e., inositol hexaphosphate (IP6), undergoes a transformations during the fermentation and drying process, and is partially converted into lower forms of phytate, ranging from IP2 to IP5. Arabinoxylans are found in higher quantity in wheat DDGS than in maize DDGS, making them a theoretically candidate for xylanase supplementation of swine feeds, although beneficial effect has not been observed to date (Widyaratne et al., 2008).

Table 2. Content (g/kg DM) of inositol phosphates and non-starch polysaccharides (NSP) of wheat, and maize, wheat/maize, and wheat distiller's dried grains with solubles[1]

		Distiller's dried grains with solubles		
Variable	Wheat	Maize	Wheat/maize[2]	Wheat
Phosphorus	4.0	8.6	10.2	11.0
Inositol phosphates				
Inositol diphosphate (IP2)	0.0	0.0	0.0	0.8
Inositol triphosphate (IP3)	0.0	0.9	0.9	0.9
Inositol quadraphosphate (IP4)	0.0	1.9	1.8	2.8
Inositol pentaphosphate (IP5)	0.0	4.5	3.3	6.4
Phytate (IP6)	13.9	9.2	6.2	8.1
Total NSP	97	192	219	229
Xylose	34	62	81	81
Arabinose	23	43	47	49

[1]Source: Widyaratne and Zijlstra (2007).

[2]Derived from the combined fermentation of wheat and maize in a 4:1 ratio.

The energy and amino acid digestibility of wheat and maize DDGS has rarely been described (Widyaratne et al., 2008). Even though wheat DDGS has a higher crude protein content than maize DDGS, lysine content and quality was higher in the maize DDGS (Table 3), because older fermentation and drying technologies prepared the batch of wheat DDGS. Maize DDGS has a higher digestible energy content, because it has a higher fat content. Without exception, phosphorus digestibility and therefore digestible phosphorus content is higher in DDGS than the parent grain.

Table 3. Standardized ileal digestible amino acid content (g/kg DM), ileal and total tract digestible energy (MJ/kg DM) and total tract digestible P (g/kg DM) contents in wheat, and maize, wheat/maize, and wheat distiller's dried grains with solubles measured in grower-finisher pigs[1]

		Distiller's dried grains with solubles		
Variable	Wheat	Maize	Wheat/maize[2]	Wheat
Amino acid				
Cysteine	4.1*d*	4.9*c*	6.6*b*	6.9*a*
Isoleucine	5.7*d*	8.4*c*	11.6*b*	12.2*a*
Lysine	3.7*bc*	4.5*a*	4.0*b*	3.4*c*
Methionine	2.7*c*	5.1*b*	5.6*a*	5.6*a*
Threonine	4.1*c*	7.3*b*	9.2*a*	9.3*a*
Tryptophan	2.0*c*	1.8*c*	2.9*b*	3.5*a*
Valine	7.3*d*	12.4*c*	15.5*b*	16.0*a*
Digestible energy				
Ileal	13.48*ab*	14.13*a*	13.18*ab*	12.59*b*
Total tract	15.91*a*	16.30*a*	14.74*b*	14.83*b*
Phosphorus	0.6*b*	5.8*a*	6.8*a*	6.8*a*

[1]Source: Widyaratne and Zijlstra (2008).

[2]Derived from the combined fermentation of wheat and maize in a 4:1 ratio.

a-d Within a row, means without a common letter differ ($P < 0.05$).

Overall, factors including the type of cereal grain used for fermentation, method of fermentation (batch or continuous), completeness or duration of the fermentation process, drying temperature and duration, and the amount of solubles blended with distiller's dried grains can affect the chemical, physical and nutritional characteristics of DDGS (Spiehs et al., 2002). The nutrient composition of DDGS should still reflect the nutrient content of original cereal grain, with a higher concentration of remaining nutrients following starch conversion and removal as ethanol and carbon dioxide (Mustafa et al., 1999).

Maize DDGS has now been available in large quantities for a decade in North America. The existence of a large variability in quality of maize DDGS is well known in the industry. Gradually the ranges in quality are been described in the scientific literature, but remain mostly descriptive in nature, whereas the underlying causes for the variability remain largely unexplored. Ten ethanol plants in a narrow geographical location (Minnesota and South Dakota) submitted each 12 maize DDGS samples in 2-month intervals. Means (dry-matter basis) and coefficients of variation among all plants were 30.2 and 6.4% for crude protein, 10.9 and 7.8% for crude fat, and 16.2 and 28.4% for acid-detergent fibre (Spiehs et al. 2002). Among the amino acids analyzed, lysine was the most variable (CV = 17.3%), followed by methionine (CV = 13.6%). Ranges in quality were not reported. This research by the University of Minnesota clearly demonstrated that variability in DDGS quality exists within and among ethanol plants, even among plants using the same fermentation and processing technology.

Some maize DDGS is marketed in the USA under specific brand names, suggesting above average and a more consistent quality. Quality control generally occurs via the monitoring of macronutrient profile, in particular crude protein content. In 10 such samples, crude protein content had a range from 246.0 to 290.7 g/kg on an as-is basis, and total lysine ranged from 4.4 to 5.9 g/kg (Stein et al., 2006). The coefficient of standardized ileal digestibility of lysine ranged from 0.439 to 0.630. The coefficient of apparent total tract digestibility of gross energy ranged from 0.627 to 0.705 among the 10 samples of maize DDGS. The largest range was found for lysine, which may be the result of heat damage during drying in some samples of maize DDGS. The measured ranges in quality were not related to any physical or chemical characteristic; however, other research suggests that specific samples of maize DDGS that are much darker, have a reduced digestibility of amino acids (Fastinger and Mahan, 2006).

In addition, 10 samples of maize DDGS were collected from a narrow geographical range in South Dakota from 10 ethanol plants (Pedersen et al. 2007). On an as-fed basis, content of crude protein ranged from 259 to 324 g/kg and ether extract ranged from 86 to 124 g/kg. The coefficient of apparent total tract digestibility of gross energy ranged from 0.739 to 0.828 and, combined with the range in gross energy content, resulted in a range in DE content from 14.42 to 16.55 MJ/kg, as fed. The range in DE content could be accurately predicted from the concentrations of ash, ether extract, ADF, and GE (Pedersen et al., 2007) and was not related to changes in colour of the DDGS samples. The existence of a range in DDGS quality, in particular ileal amino acid digestibility, was confirmed recently (Pahm et al., 2008).

For heat-treated protein feedstuffs, a critical quality characteristic is the amount of intact lysine (bioavailable) instead of total lysine. The amount of intact lysine can be measured using the reactive lysine analysis (Fontaine et al. 2007). In 80 samples of maize DDGS, reactive (intact) lysine as a percentage of crude protein ranged from 1.0 to 2.7. Interestingly, total lysine as a percentage of crude protein ranged from 2.0 to 3.5, and followed a similar pattern (Fontaine et al. 2007) when graphed against the loss of reactive lysine as a percentage of crude protein. These results indicate that reactive lysine per unit of crude protein might be a good predictor of lysine quality among samples of maize DDGS.

Fractionation of the maize prior to fermentation results in maize DDG of a different composition (Widmer et al., 2007). The maize can be dehulled and degermed, and if the solubles are not added back to the DDG at drying, the resulting product has a higher crude protein content than regular maize DDGS. The high protein DDG contained 411 g/kg of crude protein and 37 g/kg of ether extract (Widmer et al., 2007). The coefficient of apparent total tract digestibility of gross energy was 0.882 and, combined with the gross energy content, resulted in a DE content of 18.43 MJ/kg, as fed. The high protein DDG thus has a higher energy content than regular maize DDGS.

From experience in our laboratory, major contributors to DDGS variability are the amount of concentrated solubles added back and the drying process. Processing plants prefer to add back as much solubles (stillage) as possible during the drying process; otherwise they have to sell another liquid, less uniform co-product. Adding back the solubles, creates lumps when a viscous

liquid comes in contact with the drying, mash distillers' grain. A way to dissolve the lumpiness of DDGS and prevent caking in storage bins thereafter is overdrying. However, the intensity of heat, the extent of, the speed of and the equipment used for drying can cause amino acid damage. Protein damage generally becomes evident as an increasingly darker product. However, improper fermentation and excess solubles can confer a dark colour to DDGS deepen by improper drying (Beltranena and Zijlstra, 2008). In contrast to protein damage, the ethanol and DDGS production processes increases mineral bio-availability, apparently by releasing phytate-bound ions (Pedersen et al., 2007; Widyaratne and Zijlstra, 2007).

Variability of quality of canola meal

Obviously, large quality difference exists between rapeseed meal and canola meal due to the genetically reduced content of the anti-nutritional factors, mainly glucosinolates and erucic acid, in canola. These changes in quality will not be addressed, because mostly canola, not rapeseed, is used for oil production. Hexane extraction of canola oil from seed is efficient; therefore, residual oil is not expected to change much. In contrast, the protein content of canola meal ranged as much as 82 g/kg (Bell and Keith, 1991; Fan et al., 1996). Such value might be an underestimation for the entire range that exists in protein content for canola meal, based on reported ranges in protein and oil content among analyzed canola seed samples. However, greater uniformity was obtained among samples collected from a specific plant (Bell and Keith, 1991), indicating that specific sourcing of ingredients might reduce variation in nutritional quality of purchased canola meal. Gums removed early in the processing process are typically added back into the meal, causing further changes in fat content and thus quality (Spragg and Mailer, 2007). A direct comparison of digestible and available lysine has not been made among canola meal samples, but available lysine ranged from 19.8 to 23.7 g/kg among canola meal samples (Bell and Keith, 1991). Processing conditions have a major impact on lysine content and digestibility, as measured in poultry (Newkirk et al, 2003). Amino acid digestibility has been positively correlated to protein content and negatively to NSP (Fan et al., 1996), suggesting that NSP in canola meal may interfere with protein digestion (Bell, 1993). Relationships of other anti-nutritional factors in canola meal, e.g., glucosinolates and tannins, with variation in amino acid digestibility have not been reported.

Variability of quality of expeller meal and press cake

Canola expeller meal and canola press cake differ in quality due to the process used to extract the oil. With the additional heat provided prior to expelling instead of merely cold-pressing, extra oil is removed; therefore, less residual oil remains in expeller meal; 116 versus 178 g/kg (Leming and Lember, 2005). Expeller extracted meals do vary in oil content; in 41 samples the oil content ranged from 85 to 170 g/kg (Spragg and Mailer, 2007). Not surprising, the difference in efficiency of oil extraction results in large difference in crude protein content among samples of expeller meal (316 to 417 g/kg), with obvious implications for amino acid content. In oil extraction via expelling, less heat is provided than with solvent extraction. Content of residual glucosinolates ranged from 24 to 89 g/kg, but were overall higher than for canola meal (53 vs. 17

g/kg; Spragg and Mailer, 2007). The implications of the residual glucosinolate content on animal performance are less clear.

Variability of quality in crude glycerol

Specific research describing the variation in dietary energy content among samples of crude glycerol appears not to have been published to date. Glycerol content was 869.5 g/kg in one sample of crude glycerol obtained from a biodiesel facility in the USA (Lammers et al., 2008). This specific sample also contained 1.2 g crude fat/kg, 0.28 g methanol/kg, 31.9 g ash/kg, 12.6 g sodium/kg, and 18.6 g chloride/kg, indicating that some crude glycerol samples used in animal experiments contains low amounts of impurities (Lammers et al., 2008). However, the realities of commercial production of crude glycerol might be starkly different. Indeed, seven samples of crude glycerol obtained from commercial production facilities in Europe ranged from 252 to 887 g glycerol/kg, 2 to 492 g crude fat/kg, and 48 to 187 g ash/kg (Kijora and Kupsch, 1996), indicating that crude glycerol might differ in quality among commercial production facilities and that quality should therefore be monitored. The crude fat content was 156 g/kg in a sample of crude glycerol obtained from Canada (Zijlstra et al. 2009), providing further evidence that quality differences occur.

Feeding of crude glycerol may present practical problems beyond an error in estimated energy content. Methanol content should not exceed 150 ppm in glycerol used as a feedstuff. Higher levels may cause metabolic acidosis, vomiting, blindness, and gastrointestinal problems (Kerr et al. 2007). An increased NaCl content may limit dietary inclusion of glycerol to avoid that dietary Na and Cl levels exceed recommendations. Finally, glycerol is a viscous gel, which may present problems for feed mixing and flow (Kerr et al. 2007). Oxidation of residual oil in crude glycerol possesses concerns regarding the long-term stability unless antioxidants are added.

Managing ingredient variability

Precision diet formulation is becoming increasingly important to maintain competitive and sustainable of pork production systems. Animal models and proximate analyses have been used as evaluation methods for decades to describe the energy value of feedstuffs for pigs. Using these methods, average 'book' values for feedstuffs have been established (e.g., CVB, 2003; Sauvant et al., 2004), and are commonly used for diet formulations. However, these book values and evaluation methods do not allow for immediate changes in diet formulation following changes in quality of batches of co-products arriving at feed processing plants. Furthermore, the physical and proximate analyses used to support trade of feedstuffs are not the best predictors for energy values, either due to lack of repeatability among laboratories or time required to complete the analyses.

Rapid methods for estimation of energy values of feeds are required to support quick and correct decisions. Near infra-red reflectance spectroscopy (NIRS) is one of such methods. Separately, in

vitro digestibility methods have been progressively developed. These in vitro methods mimic the successive digestive processes, e.g., in the porcine gastro-intestinal tract. In vitro methods are considered rapid by some, but their main advantage is that the total extent of energy digestibility can likely be predicted more accurately than with proximate analyses and that only a few grams of feedstuff are required. Following proper validation, in vitro digestibility methods can then entirely replace in vivo determination of energy values (Regmi et al., 2008). The in vitro analyses to measure total extent of digestibility subject feedstuffs samples sequentially to a mimicked gastric and small intestinal digestion, generally using purified digestive enzymes or enzyme cocktails. Variations in the methodology exist, including methods that include a partial mimic of degradation of the non-starch polysaccharide fraction in feedstuffs. With collected samples spanning the entire quality range within a feedstuff, in vitro digestibility analyses have been able to explain more than 95% of the measured variation in energy value. The relative error of the analyses is generally less than for in vivo digestibility measurements (Regmi et al., 2008).

The advantage of the NIRS method is that it can be used as a non-invasive analysis. Samples are scanned across a wavelength spectrum (e.g., 400 to 2500 nm) by sending light into the sample. Reflected light is measured and, by difference, absorption can be determined across the entire spectrum. The changes in absorption spectra are caused by changes in chemical bonds, and these changes can be statistically related to changes in energy values or digestible nutrient content. As such, calibrations to predict the nutritional characteristics of importance for diet formulations can be developed (Van Barneveld et al., 1999). Following the collection of a robust set of samples spanning the entire range of nutritional characteristics and with a sufficient variation in quality, calibrations with a standard error of prediction of 1% can be achieved (Zijlstra, 2006). Following the effort of calibration development and validation, subsequent predictions of quality on new samples can be completed within one minute. Scans with differing profiles from maize DDGS samples seem promising for the development of calibration to predict their nutritional quality (Figure 1).

Recommendations

Biofuel co-products are feedstuffs that provide an opportunity to reduce feed cost. However, one risk of biofuel co-products is the large variation of quality introduced due to processing among co-product samples. As second risk is the use of feed quality evaluation methods that do not properly quantify the nutritional content and bio-availability of co-products high in fibre and protein. Specific procedures to manage both risks should be implemented to ensure that biofuel co-products can be effectively used to achieve predictable animal performance.

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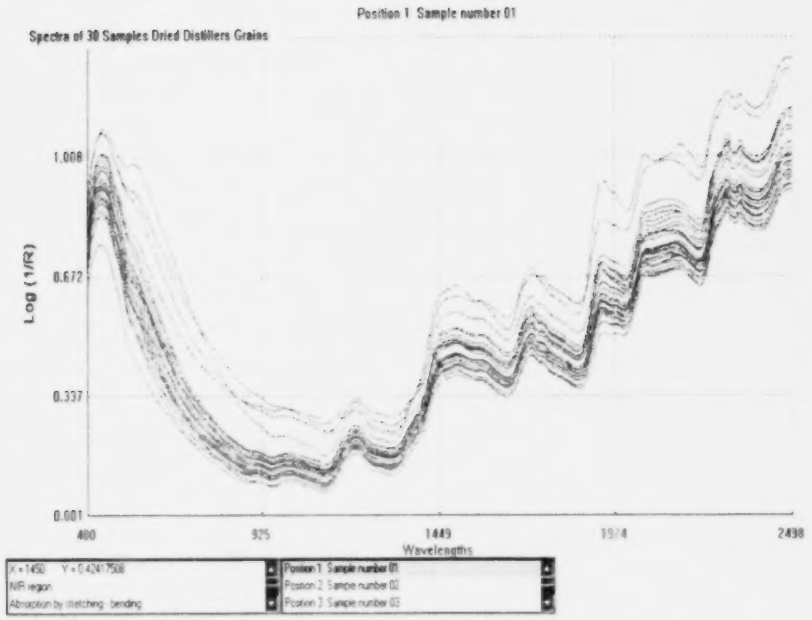

Figure 1. Near infra-red reflectance spectroscopy scans from 30 maize DDGS samples.

Appendix 8. Containing Feed Cost Using Biofuel Coproducts

Introduction

2007 was one of the most difficult years for swine producers in western Canada. Grain prices were record high and feed remains the single, most important cost of hog production. North American governments have severely distortioned the global feed market supply and demand signals. Their mandate of ethanol inclusion in fuels and the provision of subsidies for the construction and operation of biofuel plants drove demand and grain prices to the extreme. The "*can't happen fast enough*" development of the biofuels industry is primarily driven by a quest to become less dependent on middle east oil suppliers.

The consequential, rapid increase in the availability of coproducts of the ethanol and biodiesel industry, namely distiller's grain and solubles (DDGS) and canola press cake in western Canada, does not necessarily represent a low cost feed panacea for the livestock industry. Both biofuel co-products are high in dietary fibre and protein. Fibre utilization is poor in monogastric species and the hope of increased use by the mostly Alberta cattle industry will be constricted by its slow growth. Excess dietary protein contributed by these co-products could also mean greater nitrogen excretion and potentially greater harm to the environment. But widening biofuel co-product use to poultry and swine would broaden the market opportunity and address the urgent need to deal with the increasing oversupply.

This paper briefly summarizes some recent research findings and reviews some feeding strategies to optimize the inclusion and utilization of biofuel coproducts in Prairie hog diets.

Energy Values of DDGS–the Greatest Challenge

Weight gain is the main determinant of facility utilization or barn place turnover. And dietary energy is what propels hogs and broilers to grow. Starch, mainly from grain, is the primary source of dietary energy in swine diets. Fat, either added (tallow, canola oil) or intrinsic to grain or from supplemental protein sources (soy meal, canola meal) is a second source of dietary energy. Excess protein can also serve as a third source of dietary energy, but the nitrogen most be first removed and eventually excreted. Dietary fibre, that is poorly utilized by monogastric animals, which don't have the proper enzyme to breakdown the main structural bond, largely dilutes the dietary energy provided by starch, fat and broken down protein. The depletion of starch in grain resulting from its microbial conversion to ethanol and the expeller removal of oil from canola implies that both DDGS and canola press cake are high in fibre and protein.

The primary feed issue with DDGS is what "truly" is its dietary energy value. The grain stock used to ferment has the greatest impact on the dietary energy value of DDGS. Ethanol processing in North America has been more common from corn than from wheat. Some of our local plants started processing corn - wheat mixes to get the process going, and then mostly or entirely switched to wheat. But as it happened in August 2006, with high priced wheat, some reverted to fermenting corn alone or wheat - corn mixes.

Fermenting wheat concentrates the fat content from approximately 2 to 5 - 6%. Fermenting corn instead concentrates the fat content from approximately 4 to 9 -11%. Therefore, DDGS from a mix of these two grain stocks can have a fat content ranging from 4 to 12%. Because lipids provide the largest dietary energy per unit, such wide range in fat content in a DDGS grain mix, can complicate diet formulation and prediction of animal growth.

Wheat has somewhat higher fibre content than corn (3 vs. 2%). The fibre in wheat is also less digestible than corn. If whole wheat is ground and fermented without removing the bran and blended with corn, the range of fibre digestibility in a DDGS mix of both grain stocks again becomes more variable.

Fermenting corn concentrates the protein from approximately 9 to 25 - 26%. Fermenting wheat instead concentrates the protein from approximately 13 to 32 - 38%. If hog diets had higher crude protein because that's what is least-cost formulated on using a DDGS mix, nutritionist cannot have a proper handle on energy that can be provided by deaminated amino acids vs. the energy used by the animal to deaminate and excrete the excess nitrogen.

Table 1 illustrates the nutritionist conundrum regarding the range in dietary energy content of DDGS. The only manner in which a nutritionist can get a handle on the variation in nutrient provision in DDGS from constantly changing grain stocks is by conducting extensive lab testing (protein, fibre, fat, starch). Alternatively, he or she may rely on one supplier that is committed to using a single grain stock (e.g., Terra Grain Fuels, Regina). Ethanol producers are not likely to advise clients as to what their current grain stock mix is. Perhaps CFIA could step in and enforce description of the grain stock or mix in the labelling of DDGS.

Table 1. Apparent ileal and whole tract digestibility coefficients for gross energy and calculated DE and NE content of wheat[1-5], corn[5] and triticale[5] DDGS (DM basis)

	Wht[1]	Wht[2]	Wht[3a]	Wht[3b]	Wht[4]	Wht[5]	Corn[5]	Triticale[5]
Ileal dig, %	65.6	47.3	-	-		62.9	60.5	68.2
Whole tract dig, %	77.4	66.6	59	74	71.8	78.8	71.6	72.1
DE, Mcal/kg	4.02	3.39	3.00	3.59	3.83	4.29	3.78	3.82
NE, Mcal/kg	2.38	-	1.78	2.22	2.42	2.74	2.46	2.49
Pig AA status	++	--	??	??	++	++	++	++

[1]Widyaratne and Zijlstra 2007

[2]Nyachoti et al. 2005

[3]Sauvant et al. 2004 (a < 7, b > 7% residual starch)

[4]Yañez et al 2007

[5]Zijlstra and Beltranena 2007

The only manner in which a nutritionist can predict animal growth juggling such wide variation in ingredient nutrient provision is by utilizing the net energy system. He or she can then gain advantage of the higher fat content while reduce the negative impact on performance of both high fibre and excess protein in DDGS.

Fibre Digestibility of DDGS –Contribution to Energy

As introduced before, the extent of fibre digestibility in DDGS will depend on the grain stock fermented (e. g., corn, wheat, barley) and processing. Mechanical removal of the hull from barley or the bran from wheat prior to fermentation will reduce unsoluble fibre content and consequently increase the energy value of DDGS. But the incognita is to what extent the microbial fermentation during ethanol production modifies fibre digestibility for the pig. We have no answer to this question, but the proportion of solubles (stillage) added back to DDG during the drying most likely increases soluble fibre content and the variability in fibre digestibility.

If microbial fermentation makes more fibre soluble to the pig or its hindgut bacteria, can we further enhance its utilization by adding feed enzymes? Again, depending on the grain stock, addition of xylanase, cellulose and even protease feed enzymes to hog diets containing DDGS may enhance its fibre and protein digestibility. Unfortunately our preliminary results (Yañez et al. 2007) did not show that addition of xylanase to DDGS increased energy digestibility (Figure 1). However, we have not thoroughly tested xylanase addition yet nor the inclusion of multi-enzyme cocktails.

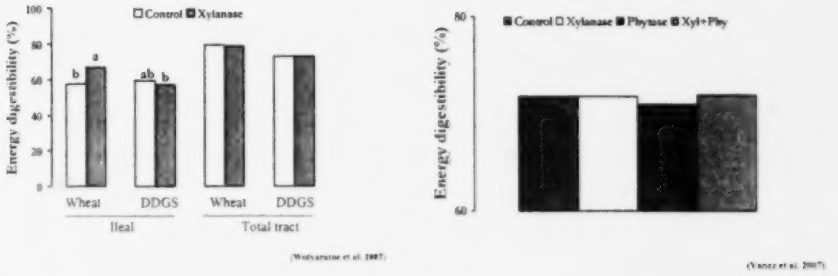

Figure 1. The effect of xylanase addition to wheat or wheat DDGS (left; Widyaratne and Zijlstra 2007) and the effect of xylanase, phytase or xylanase + phytase on the energy digestibility of wheat DDGS (right; Yañez et al. 2007)

Amino Acid Availability of DDGS –Processing Effects

The high content of protein in DDGS is perceived as a main beneficial property of this ethanol co-product. Our lower enthusiasm about this has more to do with the high protein content in the companion grains used in western Canadian hog diets than the protein content of DDGS per se. Due to the expected abundance, DDGS prices could go so low that inclusion rates would be pushed as high as possible in hog diets.

If hog diets are formulated on the basis of total protein or amino acids, there will be first an unaccounted additional energetic cost to the animal regarding the deamination and excretion of the excess nitrogen. Second, there will be a consequential increase in nitrogen excretion. Again, using the net energy system is the only way nutritionist can discount the ingredient value due to excess protein and lessen nitrogen excretion.

A second concern we have with DDGS is processing. Swine producers and the feed industry must understand what type of DDGS they are buying. Some plants will do wet milling and remove the wheat gluten prior to fermenting reducing the protein content of their DDGS (e.g., Permolex, Red Deer). Other plants will establish contracts with grain growers to ferment a low-protein wheat (Andrew; e.g., Terra Grain Fuels, Regina) resulting in lower protein DDGS.

Major contributors to DDGS variability are the amount of concentrated solubles added back and the drying process. Processing plants prefer to add back as much solubles (stillage) as possible during the drying process; otherwise they have to sell another liquid, less uniform co-product. Adding back the solubles, creates lumps when a viscous liquid comes in contact with the drying, mash distillers' grain. A way to dissolve the lumpiness of DDGS and prevent caking in storage bin thereafter is overdrying. However, the intensity of heat, the extent of, the speed of and the equipment used for drying can cause amino acid (building blocks of protein) damage. Protein damage generally becomes evident as an increasingly darker product. However, improper fermentation and excess solubles can confer a dark colour to DDGS deepen by improper drying (scorching).

Table 3. Total content (left) and apparent ileal amino acid digestibility coefficients (right) of corn, triticale and wheat DDGS as 30% replacement of a basal diet (85% wheat, 10% SBM)

	89% DM	92% DM	92% DM	92% DM				
	Basal	Corn	Triticale	Wheat	Basal	Corn	Triticale	Wheat
AA, %	Diet	DDGS	DDGS	DDGS	Diet	DDGS	DDGS	DDGS
Arg	0.96	1.09	1.15	1.41	82.3	78.6	83.0	91.9
His	0.43	0.59	0.61	0.73	81.7	64.5	73.1	86.5
Iso	0.68	1.01	1.03	1.21	78.3	66.9	75.0	88.7
Leu	1.26	2.34	2.39	2.54	80.3	80.1	85.5	94.8
Lys	0.69	0.61	0.69	0.96	67.8	46.0	50.2	71.3
Avail. Lys	-	0.41	0.53	0.88	-	0.19	0.27	0.63
Met	0.27	0.44	0.48	0.52	80.4	74.0	81.1	92.0
Cys	0.32	0.49	0.49	0.59	76.0	59.8	63.7	88.0
Phe	0.87	1.36	1.36	1.71	81.6	80.4	85.9	93.4
Tyr	0.49	0.91	0.94	1.28	78.8	81.3	88.8	95.9
Thr	0.57	0.93	0.92	1.06	72.6	66.1	70.6	83.1
Try	0.22	0.15	0.17	0.25	79.6	69.4	72.4	84.2
Val	0.79	1.18	1.22	1.38	76.1	67.1	74.4	89.1
AAProt	17.5	22.6	23.2	28.5	78.9	69.6	75.1	87.8
ProtLeco	18.4	26.3	26.9	32.6	83.5	65.5	66.5	84.2

Zijlstra and Beltranena 2007

The best criterion we have to test for drying damage to protein is bioavailable lysine (Table 3). Lysine is the first limiting amino acid for swine and the one most likely to become heat-damaged. However, testing for bioavailable lysine is expensive and not routinely conducted by local feed labs. The Hunter colour (a, b, c) is a fast method to gauge protein damage but the University of Minnesota is working on an optical, more reliable method to correlate with protein damage (Pedro and Jerry 2007). Near infrared spectroscopy (NIRS) is another rapid method that we are pursuing to eventually DDGS quality (IFASA – Feed Quality and Supply Program). Commercial feed mills could monitor DDGS quality by scanning samples at receiving and adjusting their DDGS nutrient matrix accordingly.

Due to the variability in grain stock and processing, total protein and amino acid content range widely in DDGS but probably not as much as its dietary energy value. Table 3 summarizes the amino acid content and our apparent ileal digestibility coefficients for a good wheat DDGS sample (Husky Energy, Lloydminster) and two not so good, darker samples of corn and triticale DDGS. These data proved that detailed chemical analyses plus animal digestibility results are important to understand coproduct variability.

Phosphorus in DDGS –Enhancing Its Availability

Phosphorus content concentrates two to three times in DDGS with respect to the parent grain stock. And microbes (primarily yeast) used in the ethanol process increase mineral availability somewhat. Thus, the larger the inclusion of DDGS in the diet, the lower the consequential need to supply phosphorus from inorganic sources (e.g., mono/dicalcium phosphate), resulting in feed cost savings.

We have also tested if feed phytase enzyme can further increase phosphorus availability from wheat DDGS. Our preliminary results showed a positive response to phytase addition in a semi-purified diet (Yañez et al. 2007).

Feeding DDGS –High Levels of Inclusion

Assuming that the cost is low, one has confidence on the nutrient matrix of DDGS and has considered the concerns described before, how high can one push the inclusion of DDGS in hog diets? Two additional concerns arise at high inclusions: one is palatability and voluntary feed intake; the other is the effect on carcass and pork quality.

Local results suggest that good quality corn DDGS can be included in hog diets up to 25% of the diet without negative effects on feed intake (Table 4; Young and Campbell 2007). Nonetheless, trial data evaluating the effect of high levels of wheat DDGS inclusion on feed intake and performance were not publicly available at writing. But the practical dietary inclusion levels of wheat DDGS in Prairie hog diets is likely to be lower compared to the high inclusion levels of corn DDGS in American corn-based diets. With our high protein Prairie grains in contrast to corn, it doesn't take much for excess protein to constrain wheat DDGS inclusion levels.

Table 4. Effect of feeding increasing levels of corn DDGS on grow-finish performance in a commercial facility in Alberta

	Corn DDGS, %							*P* <	
Item	0	5	10	15	20	25	SED	Linear	Quad
# replications	8	8	8	8	8	8			
Day 0 to 25									
ADG, kg/d	0.942	0.977	0.961	0.951	0.963	0.947	0.015	0.77	0.14
ADFI, kg/d	2.02	2.10	2.06	2.01	2.05	2.02	0.033	0.31	0.29
F:G	2.15	2.15	2.15	2.11	2.13	2.13	0.027	0.32	0.65
Day 25 to 53									
ADG, kg/d	0.931[a]	0.974[b]	0.966[b]	0.963[ab]	0.981[b]	0.987[b]	0.017	0.01	0.46
ADFI, kg/d	2.63	2.71	2.63	2.55	2.68	2.59	0.041	0.15	0.98
F:G	2.83[a]	2.78[ab]	2.73[bc]	2.64[cd]	2.74[b]	2.63[d]	0.043	0.01	0.32
Day 0 to 53									
ADG, kg/d	0.936[a]	0.975[b]	0.964[b]	0.958[ab]	0.972[b]	0.967[b]	0.012	0.05	0.14
ADFI, kg/d	2.33	2.41	2.36	2.29	2.38	2.31	0.029	0.12	0.48
F:G	2.49[a]	2.47[a]	2.45[a]	2.39[c]	2.45[a]	2.39[c]	0.026	0.01	0.16
Feed cost, $/kg gain[e]	0.405	0.405	0.405	0.399	0.413	0.411	0.004	0.08	0.11
IOFC, $/pig[f]	39.4	40.7	40.4	40.5	40.2	40.1	0.64	0.58	0.11

[a,b,c,d]Means with different superscript letter differ ($P < 0.05$)

[e]Wheat $105, soybean meal $270, peas $130, Canola $120, corn DDGS $123, tallow $470/tonne

[f]Income over feed cost. Pig price = $1.3 kg dressed

Young and Campbell 2007

DDGS –Effects on Carcass and Pork Quality

Assuming no detrimental effect of feed intake, the next concern with high inclusions of DDGS is the effect on carcass and pork quality. Feeding DDGS results in a marginal decrease in carcass dressing percent (Thacker 2006). As per barley-based diets, the gut compensates to handle the higher fibre content of

DDGS in comparison to soybean meal - wheat diets. The thicker, heavier gut becomes a larger proportion of the live animal. If market weight is not increased marginally (e. g, ~2 kg), removal of the gut at evisceration results in a lighter warm carcass weight.

Regarding pork quality, high corn DDGS inclusions are a greater concern than high wheat DDGS inclusions would be because nearly twice the fat content. Furthermore, the type of fat in corn DDGS is unsaturated, like in canola press cake.

Feeding unsaturated fats to hogs is known to cause soft or "fluffy" bellies. Bacon slabs don't slide well and bacon strips tend to stick together at cooking. The taste and texture of lean pork become oily and mushy at chewing. Sausage quality is greatly reduced increasing the oily sweat off and reducing wiener firmness.

As per the Alberta study of Young and Campbell (2006), increasing levels of corn DDGS up to 25% did not increase backtfat thickness at the grading site. Not much American pork quality information is publicly available for higher inclusion rates of corn DDGS. It is possible, therefore, that the packer may be unaware of the detrimental impact of high corn DDGS inclusion on pork quality until pork processing.

Feeding decreasing levels of DDGS as hogs approach market weight is a strategy that should reduce feed cost and mitigate the negative effects on pork quality. We have proposed such study including detailed pork quality work to be conducted at AAFC Lacombe Research Centre.

Low cost DDGS and eventually canola press cake should be a flag to packers to more closely monitor pork quality. With the new requirements of country of origin label (COOL), it will be easier for consumers to associate a country with mushy, oily pork.

Canola Press Cake –Feeding Considerations

Almost no research data is available yet for feeding canola press cake. It is an even more novel biofuel coproduct in comparison to DDGS. However, much can be inferred from previous Canadian research on feeding full-fat canola seed and solvent-extracted canola meal. We are currently establishing nutrient digestibility coefficients for a commercially available product.

The main issue with this co-product will be the variability in residual oil content after pressing. If the co-product originates locally from farmers making biodiesel, the residual oil content should be higher than if produced commercially (e. g., approximately 12% fat). Therefore, fat analysis should be requested in addition to protein and moisture content at testing.

If cost were low, as per the DDGS trend, the two main issues restricting canola press cake inclusion rates in hog diets would be palatability (feed intake) and the effect on carcass and pork quality (discussed before).

Glycerol is a co-product of biodiesel production. Glycerol is primarily used in the manufacturing of soaps, but can also be fed to livestock. At 10% inclusion rate, it resulted in similar growout performance to hogs fed a corn-soybean meal diet. At 20% inclusion, it caused flow problems with mash feed. Lammers and coworkers (2007) therefore concluded that 10% inclusion in hog diet was the most practical level.

Conclusions

We view the feeding of biofuel co-products as the way of the future as we enhance the food, feed and bioindustrial multi-use of raw agricultural commodities.

The issues surrounding the nutrient variability of DDGS are a concern to reliably predict animal performance. Knowing the main grain stock, some processing details, adopting rapid scanning (NIRS) technology and formulating hog diets using the net energy system, should go a long way to contain feed cost for hog producers. But as the availability increases and co-product cost decreases, pork quality -if not voluntary feed intake first-, may be what will ultimately determine the high levels of dietary inclusion of biofuel co-products.